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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
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A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host

II. INFECTION STUDIES WITH PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX

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SUMMARY

1. A detailed study of 2 biologic forms of *Puccinia graminis tritici* was undertaken to determine whether or not their reaction on the differential hosts remained consistent under various environmental factors. At the same time the influence of environmental factors on the growth of the differential hosts and on the development of the disease was determined.

2. The environmental factors controlled in this investigation were soil temperature, soil moisture, and air temperature. A relative humidity of between 95 and 100 per cent was maintained in all experiments. Both the intensity and duration of sunlight varied from day to day, but the total hours of sunshine was recorded for each experiment.

3. In no instance was the general type of infection of a biologic form on a differential host changed (1) by any of the environmental factors to which the differential host and biologic form were submitted, (2) by the source of the inoculum, or (3) by the source of seed of the differential hosts.

4. In the main the types of infection obtained with the 2 biologic forms on the differential hosts checked with those worked out by Stakman and Levine. A heterogeneous type of infection was obtained on 3 Durum varieties instead of a type reported by Stakman and Levine.

5. The best development of the differential hosts at the seedling, stooling, jointing, and heading stages occurred at 15° and 20° C. Temperatures of 10° and below resulted in a slow growth, while temperatures of 25° and 30° inhibited the growth of the plants.

6. The optimum temperature for initial infection with Form III is about 25° C., while with Form IX it is nearer 20°. The temperature range suitable for initial infection with Form IX is about 5° lower than with Form III.

7. The optimum temperature for the development of the disease with both forms on plants in the seedling, stooling and jointing stages was between 20° and 25° C. No infection occurred at temperatures of 10° and below, while only a few plants of some differential hosts were infected at 15° and 30°. With plants at the heading stage a lower optimum temperature for infection occurred in that no rust developed at 30°, while it did at 10°.

8. The temperatures at which the plants make their best growth are generally the same as those at which the best development of the disease takes place.

9. The period of incubation of Form IX has been extended over a long length of time (7-9 weeks) by submitting inoculated plants to a low temperature. The length of this period depends not only on the temperature, but also on the stage of development of the organism in the leaf tissues of the host.

A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host

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INTRODUCTION

Stakman and Levine[1] have shown that *Puccinia graminis tritici* (Pers.) Erikss. and Henn. consists of a number of biologic forms, which can be determined by their action on different varieties of *Triticum* species. To date 37 such biologic forms have been identified by them thru the parasitic action on 12 differential hosts chosen from a large number of varieties of *Triticum* species.

To determine whether these biologic forms remain constant in their behavior under various environmental conditions, a detailed study of the host-parasite relation was undertaken with 2 of these forms, following as closely as possible the methods worked out by Stakman and Levine. At the same time an opportunity was afforded to determine the influence of environmental factors on the growth of the host plants and on infection and development of the disease.

The various soil and air temperatures employed were held constant in all instances. The same soil moisture was maintained in all experiments where it was controlled. In all experiments the relative humidity was maintained between 95 and 100 per cent. Sunlight varied from day to day, but the total hours of sunshine was recorded for each experiment.

EXPERIMENTAL METHODS

No attempt will be made at this time to give a complete description of the constant temperature equipment used, owing to the fact that improvements are being made from time to time. Humidity controls have not been perfected and

[1] Stakman, E. C. and Levine, M. N.—The Determination of Biologic Forms of *Puccinia graminis* on *Triticum* spp. Minn. Agr. Exp. Sta. Tech. Bul. 8; 10 p., fig. 1, 1922.

the light factor still remains to be solved. It can be stated, however, that thru the use of refrigeration and automatically controlled electric heating units a series of temperatures from 5° to 30° C. were readily obtained. The principle involved was the cooling of a large room in the greenhouse. In this room were placed the cases in which the plants were grown. The heating units in the cases were then regulated to the temperature desired.

The plants were grown in galvanized cans 8x14 inches. The soil used in all the experiments was a sod soil taken from the Station Farm and composted near the greenhouses. Enough soil was obtained at one time for the entire season's work. When the cans were filled, the soil was sifted and mixed at the rate of 3 parts of soil to 2 parts of clean river sand. Ten kilograms of soil were used in each can with 500 grams of sand on top to serve as a mulch. All seeds were planted to a depth of 1½ to 2 inches.

When different soil and air temperatures were desired, modified Wisconsin soil-temperature tanks and glass tops of the same dimensions as the tanks were employed (Pl. 1). The modified Wisconsin soil-temperature tanks are in principle essentially like those described by Jones[1] and Johnson and Hartman[2]. The glass tops were made of wood frames and 2 panes of glass, thus giving a dead air space. By means of a thick layer of felt nailed to the bottom of the glass tops a very snug union was made between them and the tanks. For the control of the soil temperature a heating bulb was submerged in the water of the tank and the temperature of the water regulated with a mercury thermostat. The air temperature was controlled by electric heaters set along the side of the glass top and regulated by a thermostat placed in the center of the glass top. The cans were then placed in the holes of the lid.

When both the same soil and air temperatures were desired, the lid of the tank was removed, the water drained off and the electric heaters placed in the bottom of the tank. The thermostat was placed in the center just above the union of the tank and top. The cans were then placed on a stand in the tank.

No mention will be made here of the storage batteries, relays, and other accessories needed to control temperatures,

[1] Jones, L. R.—Soil Temperature as a Factor in Phytopathology. Plant World 20; 229–237, fig. 2, 1917.

[2] Johnson, James, and Hartman, R. E.—Influence of Soil Environment on the Root Rot of Tobacco. Jour. Agr. Research 17; 41-86 2 fig., pl. 1-8, 1919.

except to state that barring the misfortune of losing the plants on several occasions, the cases gave very satisfactory results.

The incubation chambers as already described[1] were modified Wisconsin soil-temperature tanks with a false bottom of slats and a tightly fitting cover of glass sash. Constant temperatures were obtained thru the use of a heating bulb controlled by a mercury thermostat.

Records of both soil and air temperatures were taken 3 times a day, the soil temperature at a depth of 3 inches and the air temperature from a thermometer hung just above the thermostat. The range of variation of the temperature in the cases was never more than one degree either way during the course of an experiment.

The method described in some detail by Goss [2] was used in determining and maintaining soil moisture. In the experiments reported on here, the soil moisture is expressed as the per cent of the moisture holding capacity rather than as per cent of dry weight. The same soil moisture, 68.2 per cent of the moisture holding capacity (23.8 per cent dry weight), was used in all experiments in the temperature cases, so that this factor remained as nearly constant as it was possible to maintain it.

Relative humidity was recorded with a Mitthof hair hygrometer. All readings were made with the doors of the cases closed, as extreme variations were recorded if an attempt was made to read these hygrometers at close range with the doors of the cases open. For the purpose of our study, the humidity, while rather high and not satisfactory to the best development of the host, was favorable for the maximum development of rust. Unless otherwise noted, the relative humidity maintained in the cases was 95 per cent or higher.

Sunlight was the most variable factor dealt with during the course of this investigation in that both the intensity and the duration of sunshine varied from day to day. During the winter months when the daily duration of sunshine was short, little or no rust developed. The total hours of sunshine prevailing during the course of all experiments were recorded.

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[1] Peltier, G. L.—A Study of the Environmental Conditions Influencing the Development of Stem Rust in the Absence of an Alternate Host. I. The Viability of the Uredinio-spores of *Puccinia graminis tritici* Form III. Neb. Agr. Exp. Sta. Res. Bul. 22; 16 p., fig. 3, 1922.

[2] Goss, R. W.—Relation of Environment and Other Factors to Potato Wilt Caused by *Fusarium oxysporum*. Neb. Agr. Exp. Sta. Res. Bul. 23; 84 p., fig. 5, 1922.

It is hoped that within another year this difficulty will be solved thru the use of artificial lighting, so that this factor can be kept under control.

SOURCES OF MATERIAL

Inoculum of the biologic forms was kindly supplied by Dr. E. C. Stakman and Mr. M. N. Levine of the Minnesota Agricultural Experiment Station. During the season of 1921-1922, Form III was used. This form was described by Levine and Stakman[1]. Kanred, resistant to many of the other biologic forms, is very susceptible to this form, while Arnautka, Mindum, Speltz Marz, Kubanka, and Emmer are resistant.

Form IX, described by Stakman and Levine,[2] was used during the season of 1922-1923. To this form Kanred is resistant, while Arnautka, Mindum, Speltz Marz, Kubanka, and Emmer are susceptible.

These forms were chosen because of their behavior on the varieties mentioned above. In one case then Kanred was susceptible and the others resistant, and in the second case Kanred was resistant while the other varieties were susceptible.

TABLE 1.—*List of differential hosts used in the study of the biologic Forms III and IX*

Triticum compactum
Little Club, C. I. No. 4066
Triticum vulgare
Marquis, C. I. Nos. 3641 and 3276
Kanred, C. I. No. 5146
Turkey Red, C. I. Nos. 1558 and 1571
Kota, C. I. Nos. 6248 and 5878
Tricticum durum
Arnautka, C. I. Nos. 1493, 1494, 4064, and 4072
Mindum, C. I. No. 5296
Speltz Marz (Arnautka), C. I. No. 6236
Kubanka, C. I. Nos. 1440, 2094, 4063, and 6519
Acme, C. I. No. 5284
Triticum monococcum
Einkorn, C. I. No. 2433
Triticum dicoccum
White Spring Emmer (Vernal), C. I. No. 3686
Khapli, C. I. No. 4013

The seed of the differential hosts was obtained for the most part from the Office of Cereal Investigations, Bureau of Plant Industry, United Department of Agriculture. In some instances several Cereal Investigations accession numbers of

[1] Levine, M. N., and Stakman, E. C.—A Third Biologic Form of *Puccinia graminis* in Wheat. Jour. Agr. Research 13; 651-654, 1918.
[2] Loc. cit.

one variety were used at one time or another in the experiments. The various varieties with the Cereal Investigations accession numbers are listed in Table 1. Owing to the fact that Turkey Red is so widely grown in Nebraska, it was included in the investigation along with the other differential hosts.

INOCULATION TECHNIC

For routine inoculation of stock plants and seedling experiments, the methods already described [1] were employed. The standard time for the incubation of the inoculated material was 48 hours.

Two methods of inoculating the plants grown in the cases were used. At the beginning of the work, definite amounts of spore suspensions were sprayed on the plants. However, the results were not always uniform, so the following method was resorted to. A definite amount of dry urediniospores was placed on a sheet of paper, and after the plants in the cases were well sprayed with water a sudden puff was given the spores on the paper, so that they settled down on the plants in a uniform fashion. This method of inoculation corresponded to as near natural infection as could be devised.

During the course of the season only one biologic form was used, so that there was no danger from mixing the forms of rust. Further, the experiments were started late in the fall and closed in the spring to lessen the danger of outside contamination by wind-borne urediniospores.

EXPLANATION OF THE SYMBOLS USED IN THE TABLES

For the sake of clearness, uniformity, and ease of comparison, the number of plants infected is expressed in percentage of plants inoculated.

In working out a set of symbols to express the degrees of infection the numerals 1 to 5 were employed, for the reason that these can be remembered more easily than any other type of symbol. In all instances the range of infection is given rather than the mean. The writer used these symbols from the standpoint of indicating the number of uredinia per leaf rather than from the standpoint of whether the uredinia were subnormal or normal in development.

The types of infection are expressed in the same manner as used by Stakman and Levine with slight modifications. In

[1] Loc. cit.

Table 2 are listed both the degrees and the types of infection as adapted for our use from Stakman and Levine.[1] In recording the type of infection the writer may have stressed the size of the uredinia more than the other differences which appeared. It is suggested that a careful study of Table 2 and the plates be made to have the degrees and types of infection well in mind before the other tables are reviewed.

TABLE 2.—*Explanation of the symbols used to indicate degrees and types of infection in the tables*

DEGREES OF INFECTION

1.–TRACE
Uredinia very few in number (5 or less) and covering a limited surface.
2.–SLIGHT
Uredinia few in number (5 to 10).
3.–MODERATE
Uredinia moderate in number (10 to 25).
4.–CONSIDERABLE
Uredinia fairly numerous and scattered (25 to 50).
5.—ABUNDANT
Uredinia very many (50 or more), covering a large area of the affected host.

TYPES OF INFECTION

0.–IMMUNE
No uredinia developed; hypersensitive flecks usually present, but sometimes there is apparent absolutely no trace of mycelial invasion in the host tissues (Pl. 5, A).
1.–VERY RESISTANT
Uredinia minute and isolated; surrounded by sharp, continuous, hypersensitive, necrotic areas (Pl. 8, A).
2.–MODERATELY RESISTANT
Uredinia isolated, and small to medium in size; hypersensitive areas present in the form of necrotic halos or circles; pustules often in green, but slightly chlorotic islands.
3.–MODERATELY SUSCEPTIBLE
Uredinia medium in size; coalescence infrequent; development of rust somewhat subnormal; true hypersensitiveness absent; chlorotic areas, however, may be present (Pl. 5, C).
4.–VERY SUSCEPTIBLE
Uredinia large and coalescence frequent; true hypersensitiveness entirely absent, but chlorosis may be present when cultural conditions are unfavorable (Pl. 2, B).
X.–HETEROGENEOUS
Uredinia very variable, apparently including all types and degrees of infection on the same blade; no mechanical separation possible; on reinoculation small uredinia may produce large ones, and *vice versa*. Infection ill defined (Pl. 5, B).

MISCELLANEOUS SYMBOLS

(;)–Hypersensitive flecks.
(.)–Necrotic lesions.

In Tables 3 to 6 a slight departure from the above symbols was made. In recording the development of rust, the letter "F" was used to denote flecking, which normally precedes the appearance of pustules, while the letter "P" was employed to designate unruptured or rupturing uredina.

[1] L. c. cit.

EXPERIMENTAL DATA

INFLUENCE OF INCUBATION TEMPERATURE ON INFECTION OF WHEAT SEEDLINGS BY PUCCINIA GRAMINIS TRITICI FORM III

Experiment 1.—On February 24, 1922, 120 seedling plants, 7 days old, of each variety of wheat listed in Table 3 were inoculated by hand and 30 of them were placed in each of the incubation chambers. These were maintained at the temperatures of 15°, 20°, 25°, and 30° C. After a period of 48 hours incubation, they were trimmed to one leaf and

TABLE 3.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form III*

Experiment 1

Variety	Days after inoculation	Per cent of plants infected at				Degrees of infection at				Types of infection at			
		15°C.	20°C.	25°C.	30°C.	15°C.	20°C.	25°C.	30°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	6	*	83	100	*	1	1–3	1–5	1–2	F	F	P	F
	8	43	90	100	50	1–3	1–4	3–5	1–2	P	P	P	P
	10	50	97	100	59	1–3	1–4	3–5	1–2	3–4	3–4	3–4	3–4
	14	50	97	100	59	1–3	1–4	3–5	1–2	4	4	4	4
Marquis C. I. No. 3641	6	0	*	100	*	...	1	2–5	1	...	F	P	F
	8	7	40	100	48	1–2	1–3	2–5	1–3	P	P	P	P
	10	13	40	100	52	1–2	1–3	2–5	1–3	3–4	3–4	3–4	3–4
	14	13	40	100	55	1–2	1–3	2–5	1–3	4	4	4	4
Kanred C. I. No. 5146	6	*	100	100	*	1	3–4	5	1–2	F	F	P	F
	8	40	100	100	26	1–3	4	5	1–2	P	P	P	F–P
	10	68	100	100	26	1–3	4	5	1–2	3–4	3–4	3–4	3–4
	14	68	100	100	29	1–3	4	5	1–2	3–4	4	4	4
Turkey Red C. I. No. 1558	6	0	*	80	0	...	1	1–5	...	...	F	P	...
	8	7	27	89	4	1	1–2	1–5	1	P	P	P	P
	10	7	27	89	4	1	1–2	1–5	1	4	3–4	3–4	3–4
	14	11	27	89	4	1	1–2	1–5	1	4	4	4	4
Kota C. I. No. 6248	6	17	97	100	52	1–3	1–3	1–4	1–2	F	F	F	F
	8	76	97	100	63	1–3	1–4	3–4	1–2	P	P	P	P
	10	83	97	100	63	1–3	1–4	3–4	1–2	3–4	3–4	3–4	3–4
	14	83	97	100	67	1–3	1–4	3–4	1–2	4	4	4	3–4
Kubanka C. I. No. 1440	6	*	87	96	0	1	1–4	1–4	...	F	F	P	...
	8	57	87	96	25	1–3	1–4	1–5	1	P	P	P	P
	10	78	100	96	25	1–3	1–4	1–5	1	X	X	X	X
	14	78	100	96	25	1–3	1–4	1–5	1	X	X	X	X
Einkorn	6	*	100	100	*	1	2–4	5	1	F	F	F	F
	8	80	100	100	71	1–4	2–4	5	1	P	P	P	P
	10	80	100	100	86	1–4	2–4	5	1–2	3–4	3–4	3–4	3
	14	80	100	100	86	1–4	2–4	5	1–2	3–4	4	4	4
Khapli C. I. No. 4013	6	43	100	100	*	1–3	1–4	3–5	1–2	F	F	F	F
	8	100	100	100	61	1–3	2–4	5	1–2	P	P	P	F
	10	100	100	100	72	1–3	2–4	5	1–2	P	P	1	1
	14	100	100	100	72	1–3	2–4	5	1–2	1	1	1	1

*Exact percentage of plants infected could not be determined, owing to indistinct flecking.
For explanation of symbols used in this table see page 9.

set on a bench in the greenhouse, the mean temperature of which, for the period of February 27 to March 10, was 27.5°. The total hours of sunshine for the period of the experiment was 105.9, a daily mean of 7.6 hours.

During incubation an even film of water occurred on the leaves of the plants held at 25° and 30° C., while only drops of water were noted on the plants kept at 15° and 20°. A summary of the results is listed in Table 3.

Of the plants incubated for 48 hours at 15° C., no flecks were found on Marquis and Turkey Red 6 days after inoculation. A trace of indistinct flecking appeared on Little Club, Kanred, Kubanka, and Einkorn, while from a trace to a moderate amount of flecks occurred on Kota and Khapli. Two days later, unruptured and ruptured uredinia were present on all varieties, the only difference being in the number of plants infected and the number of uredinia present. Ten days after inoculation the type of infection could be determined with safety. However, a final reading was made 14 days after inoculation.

The influence of a temperature of 15° C. on incubation for 48 hours was very noticeable on the reaction of the different varieties to rust. Both Marquis and Turkey Red showed but a trace to a light infection on only a small number of plants. At least 50 per cent or more of the plants of the other varieties were infected with varying amounts of rust. Khapli, the most resistant variety, as judged from the size of the uredinia, was the only one which became 100 per cent infected. In other words, while Khapli is extremely resistant to the development of rust, it is very easily infected. If we list the varieties in order of the ease of infection by rust at this incubation temperature and use the number of plants infected as a criterion, they would assume the following rank: Khapli, Einkorn, Kota, Kubanka, Kanred, Little Club, Marquis, and Turkey Red.

With 2 exceptions, practically 100 per cent of the plants of all varieties incubated at 20° C. for 48 hours produced uredinia typical for that variety. The number of uredinia was greater on all varieties at 20° than at 15°, showing that temperature played an important role during incubation in determining the number of plants infected and the amount of rust. The time required for the flecks and subsequent formation of the uredinia at 20° was somewhat shorter than that required at the lower temperature of 15°.

A temperature of 25° C. was the optimum for incubation as a large number of flecks or pustules were produced on the plants of all varieties. The period of incubation was also shortened since 6 days after inoculation uredinia were developing in many instances.

An incubation temperature of 30° C. lowered the number of plants which became infected and the degree of infection to a point almost equal to that found at a temperature of 15°. The period of incubation is also lengthened. In only one or two instances 30° was more favorable for infection than 15°. This relation was reversed with other varieties.

No influence from the various incubation temperatures was noted on the types of infection produced. These remained constant for the varieties in every instance. However, the number of plants infected and the number of uredinia were notably changed at the different temperatures. As has been pointed out before, Khapli, the most resistant to the development of rust, became easily infected, while others, like Turkey Red, susceptible to rust, were not so easily infected.

Experiment 2.—This experiment was a repetition of Experiment 1 except that a temperature of approximately 12.5° C. was maintained instead of 15° in one of the incubation chambers. Also several other wheat varieties were included. The plants were more vigorous than those in the preceding experiment owing to a greater amount of sunshine prevailing during this period. The combination of more vigorous plants and increased sunshine resulted in a higher per cent of infection, especially at 30°.

The mean temperature in the greenhouse in which the plants were benched after incubation was 23.1° C. for the period of the experiment, over 4 degrees lower than in Experiment 1. This fact probably accounts for the somewhat slower development of the uredinia. The total number of hours of sunshine for the period of Experiment 2 was 129.6 hours, a daily mean of 9.3 hours, which is an average of 1.7 hours more sunshine per day than prevailed during the course of Experiment 1. It should also be noted that 5 readings were made instead of 4 during the course of the experiment, a summary of which is given in Table 4.

TABLE 4.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici. Form III*
Experiment 2

Variety	Days after inoculation	Per cent of plants infected at				Degrees of infection at				Types of infection at			
		12.5°C.	20°C.	25°C.	30°C.	12.5°C.	20°C.	25°C.	30°C.	12.5°C.	20°C.	25°C.	30°C.
Little Club C.I.No.4066	5	0	*	*	*	...	1	4–5	1	...	F	F	F
	7	0	84	100	67	...	1–4	4–5	1–2	...	P	P	P
	9	0	96	100	73	...	1–4	4–5	1–2	...	4	4	4
	12	0	100	100	73	...	1–4	4–5	1–2	...	4	4	4
	14	0	100	100	73	...	1–4	4–5	1–2	...	4	4	4
Marquis C.I.No.3641	5	0	*	*	*	...	2–5	2–5	1–3	...	F	F	F
	7	0	100	92	100	...	2–5	5	1–3	...	P	P	P
	9	0	100	96	100	...	2–5	5	1–3	...	4	4	4
	12	0	100	96	100	...	2–5	5	1–3	...	4	4	4
	14	0	100	96	100	...	2–5	5	1–3	...	4	4	4
Kanred C.I.No.5146	5	0	*	*	*	...	1–4	2–5	2–3	...	F	F	F
	7	0	100	100	74	...	2–4	3–5	2–3	...	P	P	P
	9	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
	12	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
	14	0	100	100	74	...	2–5	3–5	2–3	...	4	4	4
Turkey Red C.I.No.1558	5	0	*	*	*	...	2–5	3–5	2	...	F	F	F
	7	0	100	100	65	...	2–5	3–5	1–2	...	P	P	P
	9	0	100	100	76	...	2–5	3–5	1–2	...	3	3	3
	12	0	100	100	76	...	2–5	3–5	1–2	...	3–4	3–4	3–4
	14	0	100	100	76	...	2–5	3–5	1–2	...	3–4	3–4	3–4
Kota C.I.No.6248	5	0	*	*	*	...	1–4	1–4	1–2	...	F	F	F
	7	0	88	100	100	...	1–4	1–4	1–3	...	P	P	P
	9	0	100	100	100	...	1–4	1–4	1–3	...	3	3	3
	12	0	100	100	100	...	1–4	1–4	1–3	...	3	3–4	3
	14	0	100	100	100	...	1–4	1–4	1–3	...	3–4	3–4	3–4
Arnautka C.I.No.1493	5	0	*	*	*	...	1–4	1–5	1–3	...	F	F	F
	7	0	100	95	100	...	1–4	1–5	1–3	...	F	F	F
	9	0	100	100	100	...	1–4	1–5	1–3	...	F	F	F
	12	0	100	100	100	...	1–4	1–5	1–3	...	1	1	1
	14	0	100	100	100	...	1–4	1–5	1–3	...	1	1	1
Kubanka C.I.No.1440	5	0	*	*	*	...	1–2	1–5	1	...	F	F	F
	7	10	95	100	100	1–2	2–4	1–5	1	F	F	F	F
	9	10	95	100	100	1–2	2–4	1–5	1	P	P	P	P
	12	10	95	100	100	1–2	2–4	1–5	1	X	X	X	X
	14	10	95	100	100	1–2	2–4	1–5	1	X	X	X	X
Acme C.I.No.5284	5	0	*	*	*	...	1–5	4–5	1–3	...	F	F	F
	7	4	87	100	100	2	1–5	4–5	1–3	F	P	P	F–P
	9	4	100	100	100	2	1–5	4–5	1–3	P	4	4	4
	12	4	100	100	100	2	1–5	4–5	1–3	4	4	4	4
	14	4	100	100	100	2	1–5	4–5	1–3	4	4	4	4
Einkorn	5	0	*	*	*	...	2	1–5	1–4	...	F	F	F
	7	0	100	100	100	...	1–5	1–5	1–4	...	P	P	P
	9	0	100	100	100	...	1–5	1–5	1–4	...	3–4	4	4
	12	0	100	100	100	...	1–5	1–5	1–4	...	4	4	4
	14	0	100	100	100	...	1–5	1–5	1–4	...	4	4	4
Emmer C.I.No.3686	5	0	*	*	0	...	1	1	...	...	F	F	...
	7	0	65	92	83	...	1–2	1–3	1–2	...	F	F	F
	9	5	75	96	96	1	1–2	1–3	1–2	F	1	1	F
	12	5	80	100	96	1	1–2	1–3	1–2	F	1	1	1
	14	5	80	100	96	1	1–2	1–3	1–2	1	1	1	1
Khapli C.I.No.4013	5	0	*	*	*	...	1–5	1–5	1	...	F	F	F
	7	0	100	100	100	...	1–5	1–5	1	...	F	F	F
	9	0	100	100	100	...	1–5	1–5	1	...	1	1	1
	12	0	100	100	100	...	1–5	1–5	1	...	1	1	1
	14	0	100	100	100	...	1–5	1–5	1	...	1	1	1

*Exact percentage of plants infected could not be determined, owing to indistinct flecking.
For explanation of symbols used in this table see page 9.

An incubation temperature of 12.5° C. appeared to be below the minimum for all varieties except Kubanka, Acme, and Emmer. Only a few plants of these varieties became infected with a trace of rust, the period of incubation being longer than at the temperature of 15° in Experiment 1.

A temperature of 25° C. during 48 hours incubation was the optimum as judged by the period of incubation, the number of plants infected, and the amount of rust developed. As in Experiment 1, an incubation temperature of 20° was the next most favorable temperature. A much larger percentage of infection occurred on all the varieties at 30° than at the same temperature in Experiment 1. On the whole, the percentage of infection and amount of rust at all the incubation temperatures, except 12.5°, was greater than in the preceding experiment and can be correlated in part with the increased amount of sunshine. No differences were noted in the types of infection produced on each individual variety.

INFLUENCE OF INCUBATION TEMPERATURE ON INFECTION OF WHEAT SEEDLINGS BY PUCCINIA GRAMINIS TRITICI FORM IX

Experiment 3.—On January 16, 1923, 150 seedling plants, 7 days old, of each of the wheat varieties listed in Table 5, were inoculated by hand and 30 placed in each incubation chamber for 48 hours. The incubation chambers were maintained at the temperatures of 10°, 15°, 20°, 25°, and 30° C. After incubation the plants were trimmed to one leaf and benched. The mean temperature of the greenhouse for the period of this experiment was 22.7°. Only 82.1 hours of sunshine was recorded for the period of the experiment, a daily mean of 5.9 hours. It was very noticeable that when the plants incubated at the temperatures of 10° and 15° were placed on a bench of the warm greenhouse, they were stimulated to a more rapid growth than the others incubated at the higher temperatures. The results of the experiment are given in Table 5.

TABLE 5.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 3

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club	6	0	0	3	0	0	...	...	1	...	...	...	...	F	...	...
C. I. No. 4066	9	0	10	20	24	0	...	1	1	1–2	...	...	3	3	3	...
	14	0	10	20	24	0	...	1	1	1–2	...	...	4	4	4	...
Marquis	6	0	0	43	3	0	...	...	1–3	1	...	...	...	F	F	...
C. I. No. 3641	9	45	20	71	18	0	1	1	1–3	1	...	3	3	3	3	...
	14	45	20	71	18	0	1	1	1–3	1–2	...	4	4	4	4	...
Kanred	6	0	0	0	0	0	...	...	...	...	...	...	...	...	...	...
C. I. No. 5146	9	22	17	33	43	24	1	1	1–3	1–2	1–2	0;	0;	0;	0;	0;
	14	22	17	33	43	24	1	1	1–3	1–2	1–2	0;	0;	0;	0;	0;
Turkey Red	6	0	3	34	12	0	...	1	1–3	1	...	...	F	F	F	...
C. I. No. 1558	9	33	30	86	24	0	1–2	1–3	1–3	1	...	3	3	3	3	...
	14	33	30	86	24	0	1–2	1–3	1–3	1	...	3	3	3	3	...
Kota	6	0	0	40	11	0	...	...	1 3	1	...	...	...	F	F	...
C. I. No. 5878	9	11	19	60	43	0	1	1	1–3	1	...	F	F	3	3	...
	14	11	19	60	43	0	1	1	1–3	1	...	3	3	3	3	..
Arnautka	6	0	0	33	20	0	...	...	1–3	1–2	...	...	...	F	F	...
C. I. No. 1494	9	40	55	70	20	3	1–2	1–3	1–3	1–3	1	F	F–3	3	3	3
	14	40	55	70	20	3	1–2	1–3	1 3	1–3	1	4	4	4	4	4
Mindum	6	0	0	24	45	0	...	...	1–3	1–2	...	...	...	F	F	...
C. I. No. 5296	9	0	23	52	52	3	...	1–2	1–3	1 3	1	...	F	X	X	X
	14	0	23	52	52	3	...	1–2	1–3	1–3	1	...	X	X	X	X

TABLE 5 CONCLUDED.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 3

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Speltz Marz	6	0	0	29	0	0	...	...	1–2	...	...	...	...	F	...	...
C. I. No. 6236	9	0	15	45	0	0	...	1	1–3	...	...	...	3	3	...	...
	14	0	15	45	0	0	...	2	1–3	...	...	...	3–4	4	...	...
Kubanka	6	0	0	14	10	0	...	...	1	1	...	...	...	F	F	...
C. I. No. 1440	9	0	0	18	10	0	...	...	1	1	...	...	...	X	X	...
	14	0	0	18	10	0	...	...	1	1	...	...	...	X	X	...
Acme	6	3	0	53	17	4	1	...	1–2	1	1	F	...	F	F	F
C. I. No. 5284	9	47	29	87	37	7	1	1	1–3	1	1	F–3	3	3	3	3
	14	47	29	87	37	7	1	1	1–3	1–2	1	3–4	4	4	4	4
Einkorn	6	0	0	90	38	0	...	...	1–4	1	...	...	...	F	F	...
C. I. No. 2433	9	4	7	97	55	0	2	1	1–5	1–3	...	3	3	3	3	...
	14	4	7	97	55	0	2	1	1–5	1–3	...	3	3–4	4	4	...
Emmer	6	0	0	17	33	0	...	...	1–4	1–3	...	...	...	F	F	...
C. I. No. 3686	9	3	18	80	47	0	1	1	1–4	1–3	...	3	F–3	F–3	3	...
	14	3	18	80	47	0	1	1	1–4	1–3	...	3	3	3–4	3–4	...
Khapli	6	0	0	86	80	25	...	...	1–4	1–4	1	...	...	F	F	F
C. I. No. 4013	9	0	7	97	100	56	...	1	1–4	1–4	1–2	...	F	F–1	F–1	F–1
	14	0	7	97	100	56	...	1	1–4	1–4	1–2	...	1	1	1	1

For explanation of symbols used in this table see page 9.

At the incubation temperature of 10° C. the majority of the varieties became infected with a trace of rust. In no instance did the percentage of infection exceed 50 per cent of the plants of any one variety. At 15° all varieties became infected but the number of plants infected and the amount of rust did not exceed that produced at 10°. Taking the varieties as a whole, more infection and a greater number of uredinia occurred at 20° and 25°, while at 30° infection took place as a rule on only a few plants of some varieties. The optimum incubation temperature for Form IX appears to be 20°, altho 25° is almost equally favorable for some varieties, as for example, Khapli. On the whole a very low percentage of infection occurred as compared with that obtained with Form III (Experiment 2), due in part to the small amount of sunshine prevailing during the course of the experiment.

Experiment 4.—This experiment was a repetition of Experiment 3. The same temperatures were maintained in the incubation chambers, and after the plants were benched the same mean temperatures occurred for the period the plants were in the greenhouse. The total hours of sunshine recorded for the period of the experiment were 95.0 hours, a daily mean of 6.8 hours. In other words, all factors influencing the results were, with the exception of sunlight, as nearly the same as it was possible to maintain them. The results as tabulated in Table 6 agree in the main with those obtained in Experiment 3. As can be noted, in only one or two instances did all the plants of any one variety become 100 per cent infected even at the optimum temperature for infection. In both experiments the number of plants infected and the number of uredinia were much smaller than those obtained with Form III. In experiments to be reported later, this same fact will be pointed out.

In conclusion it can be stated that as far as the influence of incubation temperatures on infection was concerned, the biologic forms used showed decided differences. Form III had an optimum incubation temperature of 25° while that of Form IX was nearer 20° C. In the case of Form III, infection was obtained on the majority of plants at a range of incubation temperatures of 15° to 30°, while with Form IX the range of incubation temperatures most favorable for infection on most varieties was 10° to 25°. Thus, Form IX infected wheat plants more readily at a lower range of temperature than Form III.

So far as can be determined the period of incubation at the various temperatures with both biologic forms were the same. Furthermore, these incubation temperatures had no influence whatever on the type of infection developed. These were fixed for the biologic form in question. The main differences noted were in the percentage of plants infected and in the amount of rust produced at the various incubation temperatures.

The reaction of the host plants to rust varied also. One variety responded at a stated temperature with one form of rust and not with another. Moreover, some varieties became more quickly infected than others irrespective of their relative susceptibility to these biologic forms. Still others had a limited range of temperatures at which infection might occur, while others did not seem to be so limited.

Experiment 5.—As has been shown in Experiments 3 and 4, Kanred was very resistant to biologic Form IX, while Turkey Red was susceptible. The object of this experiment was to study the behavior of Form IX on a number of more or less related varieties.

Kanred is a single head selection from Crimean (C. I. No. 1435), Turkey Red is the name most commonly used for the Crimean group of hard winter wheats grown in the United States, while Blackhull was originated as a selection from a field of Turkey Red. Of the 5 lots of Kanred seed used in this experiment all bear the same Cereal Investigations number, altho they were grown in different localities. Three lots of Turkey Red seed bearing 2 different Cereal Investigations numbers, together with Turkey Red (Nebraska check) used by the Department of Agronomy for a number of years as a check for their selected strains of Turkey Red, 2 of which were included in this experiment, were used.

On March 9, 1923, 150 seedling plants, 7 days old, of each of the varieties listed in Table 7, were inoculated by hand. Thirty plants of each variety were then incubated for 48 hours at the temperatures of 10°, 15°, 20°, 25°, and 30° C. After incubation they were trimmed and benched in a greenhouse the mean temperature of which was 24°. The total hours of sunshine recorded for the period of the experiment was 87.3 hours, a daily mean of 6.2 hours.

Only the results of the final reading are listed in Table 7, as the period of incubation and development of the uredinia was similar to that reported in Experiments 3 and 4. Altho the Kanred seed of the same Cereal Investigations number

TABLE 6.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 4

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club	6	0	17	47	10	0	...	1	1–3	1	...	...	F	F–P	P	...
C. I. No. 4066	9	0	17	50	10	0	...	1–2	1–3	1	...	...	3	4	3	...
	14	0	17	50	10	0	...	1–2	1–3	1	...	...	4	4	4	...
Marquis	6	0	13	33	57	0	...	1	1–2	1–2	...	...	F	F–P	F–P	...
C. I. No. 3641	9	13	30	33	57	0	1	1	1–2	1–2	...	3	3	3	3–4	...
	14	13	30	33	57	0	1	1	1–2	1–2	...	4	4	4	4	...
Kanred	6	0	3	7	3	0	...	1–2	1–2	1–2	...	...	0;	0;	0;	...
C. I. No. 5146	9	3	7	10	7	0	1	1–2	1–2	1–2	...	0;	0;	0;	0;	...
	14	3	7	10	7	0	1	1–2	1–2	1–2	...	0;	0;	0;	0;	...
Turkey Red	6	0	7	30	27	0	...	1	1	1–2	...	...	F	F	F–P	...
C. I. No. 1558	9	7	17	37	27	0	1	1	1	1–2	...	3	3	3	3	...
	14	7	17	37	27	0	1	1	1–2	1–2	...	4	4	4	4	...
Kota	6	13	10	24	47	0	1	1	1	1	...	F	F	F	F–P	...
C. I. No. 5878	9	23	17	31	47	0	1	1	1	1	...	3	3	3	3	...
	14	23	17	31	47	0	1	1	1	1	...	3	3	3	3	...
Arnautka	6	0	23	50	43	0	...	1–2	1–2	1–3	...	...	F	F–P	F–P	...
C. I. No. 1494	9	30	53	67	43	0	1–2	1–2	1–2	1–3	...	3	3	3	3	...
	14	30	53	67	43	0	1–2	1–2	1–2	1–3	...	4	4	4	4	...
Mindum	6	10	13	50	43	5	1	1	1–3	1–3	1	F	F	F–P	F–P	F
C. I. No. 5296	9	43	43	63	43	5	1	1	1–3	1–3	1	X	X	X	X	X
	14	43	43	63	43	5	1	1	1–3	1–3	1	X	X	X	X	X

TABLE 6 CONCLUDED.—*Influence of incubation temperature on infection of wheat seedlings by Puccinia graminis tritici Form IX*

Experiment 4

Variety	Days after inoculation	Per cent of plants infected at					Degrees of infection at					Types of infection at				
		10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Speltz Marz	6	0	3	7	18	0	...	1	1	1	...	...	F	P	P	...
C. I. No. 6236	9	20	13	10	30	0	1	1	1	1–2	...	3	3	3	3	...
	14	20	13	10	30	0	1	1	1	1–2	...	4	4	4	4	...
Kubanka	6	3	7	20	48	0	1	1	1–2	1–2	...	F	F	F–P	F–P	...
C. I. No. 1440	9	23	27	57	52	0	1	1	1–2	1–2	...	X	X	X	X	...
	14	23	27	57	52	0	1–2	1–2	1–2	1–2	....	X	X	X	X	...
Acme	6	21	38	48	31	7	1–2	1–2	1–3	1–2	1	F	F	P	F–P	P
C. I. No. 5284	9	52	59	63	31	11	1–2	1–2	1–3	1–2	1	3	3	3	3	3
	14	52	59	63	31	11	1–2	1–2	1–3	1–2	1	4	4	4	4	4
Einkorn	6	0	10	57	40	0	..	1	1–2	1	..	..	P	P	P	...
C. I. No. 2433	9	0	27	57	40	0	..	1	1–2	1	.	..	3	3	3	...
	14	0	27	57	40	0	...	1	1–2	1	...	...	4	4	4	...
Emmer	6	3	17	21	29	0	1	1	1–2	1–3	...	F	F	F–P	P	...
C. I. No. 3686	9	14	20	34	29	0	1	1	1–2	1–3	.	3	3	3	3	...
	14	14	20	34	29	0	1	1	1–2	1–3	...	4	4	4	4	...
Khapli	6	10	7	33	48	3	1	1–2	1–2	1–2	1	F	F	F	F	F
C. I. No. 4013	9	52	63	40	48	7	1	1–2	1–2	1–2	1	F–1	F–1	1	F–1	F–1
	14	52	63	40	48	7	1	1–2	1–3	1–2	1	1	1	1	1	1

For explanation of symbols used in this table see page 9.

TABLE 7.—*Influence of incubation temperature on infection of a number of related wheat varieties of the Crimean group by Puccinia graminis tritici Form IX*

Experiment 5

Variety	Cereal investigations number	Source	Per cent of plants infected at					Degrees of infection at					Types of infection at				
			10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Kanred	5146	Moccasin, Mont.	29	29	17	68	70	1	1	1	1	1	0;	0;	0;	0;	0;
	5146	Manhattan, Kan.	11	34	45	73	63	1	1	1	1	1	0;	0;	0;	0;	0;
	5146	Havre, Mont.	11	43	42	70	46	1	1	1	1	1	0;	0;	0;	0;	0;
	5146	Akron, Colo.	11	20	45	56	70	1	1	1	1	1	0;	0;	0;	0;	0;
	5146	Lincoln, Neb.	20	20	57	97	87	1	1–2	1–3	1–3	1–2	0;	0;	0;	0;	0;
Turkey Red	1558	Moccasin, Mont.	57	47	63	89	11	1–2	1–2	1–2	1–4	1	3	3–4	3–4	3–4	3–4
	1571	Moro, Ore.	17	23	52	76	11	1	1–2	1–2	1–4	1	3	3	3–4	3–4	3–4
	1558	Hays, Kan.	31	48	63	77	48	1	1–2	1–2	1–4	1–2	3	3–4	3–4	3–4	3–4
	Nebr. check	Lincoln, Neb.	43	47	40	65	33	1	1–2	1	1–4	1	3	3–4	3–4	3–4	3–4
	Nebr. No. 6	Lincoln, Neb.	38	80	46	83	48	1	1–3	1–2	1–4	1	3	3–4	3–4	3–4	3–4
	Nebr. No. 11	Lincoln, Neb.	83	83	77	93	72	1–2	1–3	1–3	1–4	1	3–4	3–4	3–4	3–4	3–4
Blackhull	....	Lincoln, Neb.	33	63	50	73	23	1	1–2	1–3	1–3	1	3	3–4	3–4	3–4	3
Crimean	1435	Lincoln, Neb.	17	27	41	90	73	1	1–2	1–2	1–4	1	3–4	4	3–4	4	4

For explanation of symbols used in this table see page 9.

had been grown in 5 different localities, no appreciable differences were noted in their individual reactions to Form IX at the various incubation temperatures. The number of plants infected and the amount of rust which developed after incubation appeared to be greater at the temperatures of 25° and 30° C. than were reported for Kanred at the same temperatures in Experiments 3 and 4.

With the 6 numbers of Turkey Red, rather large variations in the percentage of infection occurred. Another fact which appears to be quite characteristic of Turkey Red in its reaction to both biologic forms investigated was that at 30° C. it was not as easily infected as Kanred.

The percentage of the plants infected and the amount of rust were smaller with Blackhull than with either Kanred or Turkey Red (Pl. 8, C). The same was true of Crimean (Pl. 8, D).

Judging from the number of plants infected and the amount of rust and type of infection, Blackhull appears to be slightly more resistant than Turkey Red. However, no great differences existed. On the leaves of Crimean larger uredinia were produced than on either Blackhull or Turkey Red. In the case of Kanred only hypersensitive flecks developed.

INFLUENCE OF THE SOURCE OF INOCULUM ON THE DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON CERTAIN WHEAT VARIETIES FORM III

Experiment 6.—This experiment was carried out to answer the question as to whether or not the behavior of a biologic form on its host could be changed by using different sources of inoculum. Three distinct sources were used, as follows: (1) from the stock cultures grown in the greenhouse on Little Club, (2) from the same host as that inoculated, and, (3) from Khapli.

Thirty seedling plants of each variety were inoculated with each inoculum in the usual manner and incubated for 48 hours at a temperature of approximately 25° C. After incubation they were trimmed and set on a bench in a greenhouse the mean temperature of which was 24.5° for the period of the experiment. The total hours of sunshine recorded for the period of the experiment was 79.1 hours, a daily mean of 5.6 hours.

The results listed in Table 8 show rather conclusively that the same type of infection occurred on the different varieties irrespective of the source of the inoculum. The

lower percentage of infection when rust from Khapli was used was due to smaller amounts of inoculum placed on the inoculated leaves.

TABLE 8.—*Influence of the source of inoculum on the development of Puccinia graminis tritici on certain wheat varieties Form III*

Experiment 6

Variety	Source of inoculum	Per cent of plants infected	Degrees of infection	Types of infection
Little Club	Stock	100	5	4
C. I. No. 4066	Little Club	100	3–5	4
	Khapli	60	1–3	4
Marquis	Stock	100	5	4
C. I. No. 3641	Marquis	100	4	4
	Khapli	68	1–3	4
Kanred	Stock	100	3–5	4
C. I. No. 5146	Kanred	100	3–5	4
	Khapli	82	1–3	4
Turkey Red	Stock	100	5	3–4
C. I. No. 1558	Turkey Red	100	5	3–4
	Khapli	70	1–2	3–4
Kota	Stock	100	5	3–4
C. I. No. 6248	Kota	100	2–5	3–4
	Khapli	67	1–2	3–4
Kubanka	Stock	100	4–5	X
C. I. No. 1440	Kubanka	100	4–5	X
	Khapli	100	1–2	X
	Stock	100	5	3–4
Einkorn	Einkorn	100	5	3–4
	Khapli	87	1–3	3–4
Khapli	Stock	100	5	1
C. I. No. 4013	Khapli	100	1–3	1
	Kubanka	100	5	1

For explanation of symbols used in this table see page 9.

INFLUENCE OF ENVIRONMENTAL CONDITIONS UNDER WHICH SEED OF THE DIFFERENTIAL HOSTS WAS GROWN, ON INFECTION AND SUBSEQUENT DEVELOPMENT ON THE HOST PROGENY, OF PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX

Experiments 7 and 8.—In both experiments seedling plants 7 days old, of the various differential hosts listed in Table 9, were inoculated (50 each in 1922 and 30 in 1923) and incubated for 48 hours. They were then trimmed and placed on a bench in the greenhouse. The mean temperature of the greenhouse for the period of the experiment in 1922 was 22° and in 1923, 24° C. The total hours of sunshine for the period of the experiment in 1922 was 80.9, a daily mean of 5.8 hours; while in 1923 the total hours of sunshine recorded was 134.7, a mean of 9.6 hours. Thus, a total of 53.8 hours more of sunshine prevailed during the experiment in 1923 than in the experiment run in 1922.

During the growth of the plants in both experiments, notes were made on the plumpness of the seed planted and the development of the resulting seedlings. Characteristic differences were noted. A few illustrations here will suffice to demonstrate this fact. In the case of the Little Club seed grown at Moro and Corvallis, Oregon, the seedlings presented a much shorter and wider leaf than the other plants. Even at the conclusion of the experiment this characteristic was very evident. On the other hand, no gross morphological differences were noted between the seedlings of Marquis and they reacted equally to the 2 biologic forms used. The seedlings of the other differential hosts either showed characteristics like those described for Little Club or no differences were noted as in the case of Marquis. Of course, an occasional mixture of seed was encountered and these were discarded when observed.

The results given in Table 9 are, on the whole, uniform in respect to the number of plants infected, the amount of rust, and the type of infection produced by the 2 biologic forms on the seedlings of the differential hosts, irrespective of the Cereal Investigations number and the locality where the seed was grown (Pls. 2 to 8).

We can conclude from these experiments that the environmental factors under which the seed of the differential hosts was grown had no influence in changing the reaction of the progeny to a definite biologic form in any of the experiments

reported on. In this connection it would be interesting to determine how one biologic form obtained from different localities would behave on the various differential hosts.

TABLE 9. *Influence of environmental conditions under which seed of the differential hosts was grown, on infection and subsequent development on the host progeny, of Puccinia graminis tritici*

Form III and Form IX

Experiments 7 and 8

Variety	Cereal investigations number	Locality grown and crop year	Per cent of plants infected		Degrees of infection		Types of infection	
			Form III	Form IX	Form III	Form IX	Form III	Form IX
Little Club	4066	Moccasin, Mont. 1921	96	93	1–4	1–3	4	4
	4066	Moccasin, Mont. 1921	92	90	1–4	1–2	4	4
	4066	Moro, Ore. 1921	100	100	1–4	1–2	4	4
	4066	Corvallis, Ore. 1919	100	93	1–4	1–2	4	4
	4066	Lincoln, Neb. 1922	...	100	...	1–3	...	4
Marquis	3641	Moccasin, Mont. 1921	100	100	1–4	1–3	4	4
	3641	Moccasin, Mont. 1921	100	100	1–4	1–4	4	4
	3276	Aberdeen, Ida. 1921	100	98	1–5	1–3	4	4
	3641	Unknown	98	100	1–4	1–3	4	4
	3641	Lincoln, Neb. 1922	...	97	...	1–4	...	4
Kanred	5146	Moccasin, Mont. 1921	98	68	1–4	1	4	0;
	5146	Manhattan, Kan. 1919	100	73	1–4	1	4	0;
	5146	Havre, Mont. 1921	98	70	1–4	1	4	0;
	5146	Akron, Colo. 1921	90	56	1–4	1	4	0;
	5146	Lincoln, Neb. 1922	98	97	1–4	1–3	4	0;
Turkey Red	1558	Moccasin, Mont. 1921	98	89	1–4	3–4	4	3–4
	1571	Moro, Ore. 1921	98	76	1–4	1–2	4	3–4
	1558	Hays, Kan. 1921	98	77	1–4	1–4	4	3–4
Kota	6248	Moccasin, Mont. 1921	98	93	1–3	1–3	3–4	3–4
	6248	Moccasin, Mont. 1921	98	90	1–3	1–3	3–4	3–4
	5878	Dickinson, N. D. 1920	100	100	1–3	1–3	3–4	3–4
	6248	Lincoln, Neb. 1922	...	97	...	1–4	...	3–4
	5878	Minnesota	...	100	...	1–4	...	3–4
	5878	North Dakota 1922	...	100	...	1–4	...	3–4
Arnautka	1493	Moccasin, Mont. 1921	90	100	1–3	1–4	1	4
	4064	Moccasin, Mont. 1921	95	100	1–3	1–4	1	4
	4072	Corvallis, Ore. 1919	97	96	1–3	1–4	1	4
	1493	Akron, Colo.	56	100	1–2	1–4	1	4
	4064	Minnesota	...	100	...	1–4	...	4
	1494	North Dakota 1922	...	100	...	2–4	...	4
	4064	South Dakota 1922	...	97	...	1–4	...	4
Mindum	5296	Moccasin, Mont. 1921	75	100	1–2	1–4	0;	X
	5296	Cheyenne, Wyo. 1920	93	97	1–3	1–2	0;	X
	5296	Dickinson, N. D. 1920	84	100	1–2	1–3	0;	X
	5296	Dickinson, N. D. 1920	...	100	...	1–3	...	X
	5296	North Dakota 1922	...	97	...	1–4	...	X

TABLE 9 CONCLUDED.—*Influence of environmental conditions under which seed of the differential hosts was grown, on infection and subsequent development on the host progeny, of Puccinia graminis tritici*

Form III and Form IX

Experiments 7 and 8

Variety	Cereal investigations number	Locality grown and crop year	Per cent of plants infected		Degrees of infection		Types of infection	
			Form III	Form IX	Form III	Form IX	Form III	Form IX
Speltz Marz	....	Unknown	100	100	1–4	1–3	3	4
	6236	Unknown	...	69	...	1–3	...	4
Kubanka	1440	Moccasin, Mont. 1921	100	100	1–3	1–4	X	X
	4043	Moccasin, Mont. 1921	87	100	1–3	1–3	X	X
	1440	Dickinson, N. D. 1920	83	100	1–3	1–3	X	X
	2094	Unknown	88	90	1–3	1–2	X	X
	2094	Unknown	95	100	1–3	1–4	X	X
	1440	Lincoln, Neb. 1922	...	97	...	1–4	...	X
	1440	North Dakota 1922	...	93	...	1–3	...	X
	6519	North Dakota 1922	...	100	...	1–2	...	X
	1440	Minnesota	...	97	...	1–3	...	X
Acme	5284	Moccasin, Mont. 1921	100	93	1–3	1–3	4	3–4
	5284	Mandan, N. D. 1920	100	100	1–3	1–4	4	3–4
	5284	Akron, Colo. 1921	97	97	1–3	1–4	4	3–4
	5284	Unknown	93	100	1–3	1–3	4	3–4
	5284	North Dakota 1922	...	90	...	1–3	...	3–4
	5284	Minnesota	...	90	...	1–3	...	3–4
Einkorn	....	Dickinson, N. D. 1921	100	93	1–3	1–2	4	4
	2433	Dickinson, N. D. 1920	100	100	1–4	1–3	4	4
	2433	Unknown	...	100	...	1–4	...	4
	2433	Minnesota	...	100	...	1–4	...	4
Emmer	3686	Moccasin, Mont. 1921	90	100	1–3	1–3	0;–1	4
	3686	St. Paul, Minn. 1920	74	80	1	1–2	0;–1	4
	3686	Unknown	81	93	1–2	1–2	0;–1	4
Khapli	4013	Moccasin, Mont. 1921	89	97	1–3	1–3	1	1
	4013	Moccasin, Mont. 1921	94	100	1–3	1–3	1	1
	4013	Highmore, S. D. 1920	87	100	1–3	1–3	1	1
	4013	Unknown	100	100	1–3	1–3	1	1
	4013	Davis, Calif. 1922	...	100	...	1–3	...	1
	4013	Lincoln, Neb. 1922	...	100	...	1–3	...	1

For explanation of symbols used in this table see page 9.

INFLUENCE OF TEMPERATURE ON THE DIFFERENTIAL HOSTS AT DIFFERENT STAGES OF GROWTH

The experiments previously reported on have for the most part dealt with the incubation temperatures suitable for infection by the two biologic forms studied, of wheat seedlings grown in pots. We come now to the study of the influence of temperature not only on infection but also on the subsequent development of rust. At the same time an opportunity was afforded of noting the behavior of the differential hosts at the various temperatures. Four distinct stages in the

growth of the wheat plant were studied, namely: seedling, stooling, jointing, and heading. Before presenting the data on the environmental factors influencing infection a short account will first be given of the host reaction to these conditions.

Seedling stage.—Thirty-five seeds of each of the varieties listed in Tables 10 and 11 were planted in each can and notes taken on date of emergence, per cent of germination, and seedling development at the various temperatures.

At 5° C. the seedlings emerged in about 3 weeks. By the end of the seventh week the seedlings were from ½ to 4 inches in height and only the primary leaf had developed.

At 10° C. 10 to 12 days were required for the emergence of the seedlings. By the end of the seventh week the seedlings were from 6 to 8 inches in height and from 2 to 3 leaves were fully developed. An excellent growth of the seedlings occurred at this temperature as judged by the dark green color and strong upright habit of the plants.

Only 7 days were required for emergence at 15° C. The seedlings made an excellent growth, having a dark green color and upright habit. At this temperature some differences in the height of the plants of the different varieties were noted. Some varieties were 10 inches in height at the end of the seventh week, while others were only 6 to 8 inches in height. As a rule, 3 or more leaves were present.

At 20° C. the time required for emergence was shortened to 5 days. A good upright growth of the seedlings took place so that by the end of the seventh week some were 10 to 12 inches in height, while others were only 8 inches. A few varieties started to stool. The seedlings had from 4 to 5 leaves fully expanded.

Emergence occurred in 3 days at the temperatures of 25° and 30° C. The plants were not thrifty, being of a light green color and drooping. The most striking characteristic was the very pronounced elongated mesocotyl, especially at 30°. Only a few secondary roots were formed, so that seedlings grown at this temperature did not make a very thrifty growth. The seedlings grown at these temperatures were only 5 to 7 inches in height and with an average of 2 leaves.

Another interesting observation was made with Einkorn and Khapli. At temperatures of 20° C. and below, a very pronounced reddish pigmentation of the culms occurred. This pigmentation did not appear at the temperatures of 25° and 30°.

With only one or two exceptions the percentage of germination at the temperatures of 5°, 10°, 15°, 20°, and 25° C. was about the same for each variety. However, the time required for germination and emergence varied according to the temperature. At 30° the per cent of germination decreased with all varieties and this was especially noticeable with Turkey Red and Kanred.

At the conclusion of one experiment, the cans planted with Turkey Red and Kanred and held at 30° C. were set out at a lower temperature. During the course of the experiment only a few plants had come up. However, when the soil temperature was lowered, a majority of the seed which had not germinated when held at 30° germinated at this lower temperature (about 20° C.). In this instance it was purely a case of delayed germination due to unfavorable temperatures.

In conclusion it can be stated that with the exception of the seeds planted and held at 30° C. the per cent of germination was about the same at all temperatures altho the time required for germination and emergence varied according to the temperature, being shortest at 25° and 30° and longest at 5°. The best development of the seedlings occurred at 15° and 20°, altho a good but rather slow growth took place at 10°, while at 5° an extremely slow growth occurred. The number of plants included in the experiments was too small to correlate any differences in behavior of the varieties to the various temperatures, altho differences were noted from time to time.

Stooling and jointing stages.—For the study of the influence of temperature on these stages of the growth of the differential hosts, 8 seeds were planted in the cans. The cans were placed on a bench in the greenhouse until the plants started to stool when they were transferred to the various temperature cases. The first year, the plants were placed in the cases when they were about 6 to 8 inches in height and some varieties had just begun to stool. All plants had 4 to 6 leaves fully developed and all were in a good growing condition. The second year the plants were held in the greenhouse on the bench for about 2½ months. At the time these plants were placed in the temperature cases they were about 15 inches tall, with all varieties stooling and most of them jointing.

At 5° C. all varieties made a slow growth. The average increase in height made for the duration of the experiment was 3 to 9 inches. The Durum wheats appeared to make the best growth at this temperature. A little more rapid growth occurred at 10°. At 15° the spring wheats almost doubled their height during the course of the experiment. The Durum wheats appeared to make the most rapid growth at this temperature. At 20° the plants made an excellent growth, the spring wheats more than doubling their previous height. A few varieties were headed at the conclusion of the experiment.

In all instances the condition of the plants at 25° C. at the conclusion of the experiment was poorer and the growth less than at 20°. The poorer condition of the plants was still more pronounced at 30° and little or no increase in the height of the plants was noticed. Einkorn appears to be very sensitive to high temperatures. In these experiments rarely have any of the Einkorn plants remained alive at 25° and 30° at the conclusion of an experiment. Both Turkey Red and Kanred also suffered from these temperatures and produced only dwarfed plants. The other varieties made some growth at these temperatures but it was not nearly as good as at the lower temperatures. Stooling was rather general at temperatures of 20° and below. Little or no stooling occurred at 25° and 30°. The Durum wheats produced a few stools at every temperature. A temperature of 25° hastened heading, while at 30° heading was inhibited. Thus, as in the case of the seedling plants, the best and most normal development of the plants occurred at 15° and 20°.

Heading stage.—As in the case of the study of the influence of temperature on the differential hosts at the stooling and jointing stages, 4 plants were grown in the cans and held in the greenhouse until about heading time when they were transferred to the temperature cases.

With the exception of the winter wheats the plants of the differential hosts used were about to head or were heading when placed in the temperature cases. The influence of the various temperatures was very similar to that already reported on for the seedling and stooling stages. The plants in the 10° C. case made a slow but strong growth, 15° and 20° seemed to give optimum development of the plants, while at 25° and 30° little or no growth occurred. The Einkorn plants were dead at the conclusion of the experiments, showing that they are not able to survive at these higher tempera-

tures. In fact, temperatures of 25° and 30° had a more inhibiting effect on the plants at the heading stage than at the other stages discussed. Again, the best and most normal development of the plants at the heading stage occurred at 15° and 20°.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM III

Experiment 9.—On March 13, 1922, the cans held at the temperatures of 20°, 25° and 30° C. for several days were seeded with the differential hosts listed in Table 10. The seedlings were inoculated by the spray method when they were 7 days old, at which time the first leaf had developed. During the period the plants were in the cases, a daily mean of 6.5 hours of sunshine prevailed.

Owing to the method of inoculation, 100 per cent infection was not to be expected, so that the total number of plants infected was rather small, as can be seen from Table 10.

TABLE 10.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the seedling stage*

Form III

Experiment 9

Variety	Per cent of plants infected at			Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	27	22	0	1–2	1–3	...	4	4	...
Marquis C. I. No. 3641	74	11	3	2	1–3	3	4	4	4
Kanred C. I. No. 5146	40	3	0	1–3	2	...	4	4	...
Turkey Red C. I. No. 1558	53	3	8	1–5	1–2	3	4	4	4
Kota C. I. No. 6248	47	4	0	1–3	2	...	3	3	...
Kubanka C. I. No. 1440	38	0	0	1–2	...	...	X	...	...
Einkorn	32	3	8	1–3	2	3	4	4	4
Khapli C. I. No. 4013	3	9	0	1	1	...	1	1	...

For explanation of symbols used in this table see page 9.

At 30° C. only the first leaf of an occasional plant of a few varieties became infected. A few plants of all varieties but one, were infected at 25°. The number of uredinia was greater than at 30°. On the whole the degree of infection was rather light. At 20° where the plants made their optimum development the highest percentage of infection occurred on all varieties. The amount of rust was greater than at the other temperatures. Both at 20° and 25° uredinia usually occurred on the first leaf, a few on the second, with only an occasional pustule on the third leaf.

While striking differences were noted in the development of the plants, the number of plants infected, and the amount of rust at the various temperatures, in no instance was the type of infection altered by changes in temperature. The results of this experiment show that the conditions under which the plants are grown play a considerable part in infection and subsequent development of rust. The seedlings making the most normal and rapid growth rust most readily.

When the results obtained in Experiment 2 are compared with the results obtained here, it will be noted that the inoculated plants grown normally and subjected to an incubation temperature of 30° C. for 48 hours and then returned to lower temperatures produced a much higher percentage of infection. Thus, an incubation temperature of 30° for a short period gives a much higher per cent of infection than when plants are subjected to a temperature of 30° both before and after inoculation. In conclusion it can be stated that the optimum temperature for infection and subsequent development of rust was 20°.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM IX

Experiment 10.—Having installed the low temperature apparatus in the greenhouse during the summer of 1922, it was possible to use temperatures below 20° C. Accordingly the same set of conditions were maintained as in Experiment 9 with the exception of sunlight. A daily mean of 5.4 hours of sunshine prevailed during the course of the experiment. In this experiment the 6 temperatures of 5°, 10°, 15°, 20°, 25°, and 30° were employed. The plants were inoculated when 7 days old by the dusting method. The results of this experiment are summarized in Table 11.

TABLE 11.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the seedling stage*

Form IX

Experiment 10

Variety	Per cent of plants infected at						Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.*	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	0	0	0	4	28	3	...	...	...	1	1–3	2	...	...	...	4	4	4
Kanred C. I. No. 5146	0	0	0	0	10	0	...	...	...	...	1	...	...	...	...	...	0;	...
Turkey Red C. I. No. 1558	0	0	0	0	48	4	...	...	...	...	1–4	4	...	...	...	...	4	4
Arnautka C. I. No. 1493	0	0	11	11	62	5	...	...	1	3	1–3	1	...	...	3	4	3	3–4
Mindum C. I. No. 5296	0	0	0	11	50	0	...	...	...	1	1–3	...	...	...	...	X	X	...
Kubanka C. I. No. 1440	0	0	0	4	10	0	...	...	...	2	1	...	...	...	...	X	X	...
Einkorn C. I. No. 2433	0	0	3	8	31	0	...	...	1	3	1–2	...	...	...	3	3	3	...
Khapli C. I. No. 4013	0	0	0	32	29	10	...	...	...	1	1	1	...	...	...	1	1	...

*Reinoculated, as first inoculation failed.

For explanation of symbols used in this table see page 9.

Only a few plants of some varieties were infected with a trace of rust at 30° C. Considerably more rust occurred at 25°, and the plants made a more favorable growth than at the higher temperature of 30°.

The plants made a splendid growth at 20° C. and at the conclusion of the experiment some of the varieties were stooling. For some unknown reason, the first inoculation failed to produce any rust whatever, so this case was reinoculated 2 weeks later. Thus, at the conclusion of the experiment less rust was present than should be expected at this temperature, so that the results cannot be correlated with those obtained at the other temperatures.

Only an occasional plant of 2 varieties became infected with a trace of rust at 15° C. At the conclusion of the experiment, 30 days after inoculation, no rust appeared on the plants held at 5° and 10°. However, the plants in the 5° case were only 1 to 4 inches in height, and in many instances the first leaf had not expanded. Here we find that when plants are held at a constant temperature of 10° before and after inoculation, no infection occurs, altho infection did occur when plants were subjected to an incubation temperature of 10° for 48 hours and then removed to temperatures more normal for the development of the plants.

INFLUENCE OF TEMPERATURE ON DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE SEEDLING STAGE FORM IX

Experiment 11.—In Experiment 10 it was found that at the temperatures of 5° and 10° C. no infection was obtained. The object of this experiment was to determine whether or not these temperatures were too low for the development of rust, when the plants were inoculated and incubated at the optimum incubation temperature.

Accordingly seed of the several varieties was planted January 5, 1923, in the cans in the same soil and with the same soil moisture as in Experiment 10. The cans were held in a greenhouse the mean temperature of which was 23.5° C. for the period from January 5 to January 17. On January 15, the plants were inoculated by hand and incubated for 48 hours under a canvas placed over the bench on a frame upon which a fine spray of water was directed to maintain a high relative humidity. The plants inoculated were all grown under the same conditions and were of approximately the same height. After incubation the plants were set in the

TABLE 12. *Influence of temperature on the development of Puccinia graminis tritici on wheat plants at the seedling stage*

Form IX

Experiment 11

Variety	Per cent of plants infected at						Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	0	23	6	48	47	10		1	2–5	1 3	1 3	1		4	4	4	4	4
Kanred C. I. No. 5146	0	0	0	0	0	0												
Turkey Red C. I. No. 1558	0	5	26	0	6	5	...	1	1	...	1	1	...	3	3	...	4	4
Arnautka C. I. No. 1493	0	10	60	38	12	0	...	1–2	1–3	1–3	1	...	...	3–4	3–4	3	3	
Mindum C. I. No. 5296	0	0	0	0	0	10	...	...	...	...	...	1	...	...	...	...	...	X
Kubanka C. I. No. 1440	0	6	0	0	40	0	...	1	...	...	1	...	...	X	...	...	X	
Einkorn C. I. No. 2433	0	4	5	0	0	6	...	1–2	1	...	...	1	...	3	3	...	...	4
Khapli C. I. No. 4013	0	43	40	0	8	0	...	1–2	1–3	...	1	...	...	1	1	...	1	0

For explanation of symbols used in this table see page 9.

cases maintained at the temperatures of 5°, 10°, 15°, 20°, 25°, and 30°. A daily mean of 5.2 hours of sunshine prevailed during the course of the experiment.

The results at the conclusion of the experiment, February 9, 1923, are given in Table 12. It will be noted that practically the same results were obtained at 30° C. as in Experiment 10. Only a few plants of some varieties became infected with a trace of rust. At 15°, 20°, and 25° the results are, on the whole, similar to those obtained in Experiment 10. Some rust appeared in the 10° case, whereas in Experiment 10 no rust occurred. The development of rust at this temperature was very slow indeed, due both to the slow growth made by the plants and the low temperature for rust development. For example, uredinia were breaking thru on January 23 at 25° and 30°, on January 26 at 20°, on January 31 at 15°, and on February 5 at 10°. Up to that date no rust appeared at the temperature of 5°.

At the conclusion of the experiment, February 9, the plants held in the 5° C. case were removed to the cold room maintained at a temperature of 5° or below. On March 20, 9 weeks after inoculation, not one uredinium was observed on any of the plants. The plants were then transferred to a warm greenhouse and left for 6 days, after which time the plants were carefully examined and some plants were found infected, as follows: 2 plants of Turkey Red, 6 of Arnautka, 6 of Einkorn, and 3 of Khapli. The mean temperature of the greenhouse for this 6-day period was 23°.

Here we have an instance where seedlings were inoculated and incubated at 23° C. for 48 hours, and then held at a temperature of 5° or below for 9 weeks. At the conclusion of this period no rust was visible; but on transferring the plants to a mean temperature of 23° for 6 days, rust appeared.

An incubation temperature of 23° C. did not have any influence on the development of rust when the plants were subsequently grown at temperatures of 15° and above. However, this is to be expected. At 10° some rust did develop, while in Experiment 10 no rust developed when the plants were inoculated at 10° and the plants maintained at this temperature for 30 days. A temperature of 5° simply lengthened the period of incubation until the plants were removed to a temperature more favorable for the development of rust.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE STOOLING AND JOINTING STAGES FORM III

Experiment 12.—On January 4, 1922 the cans containing the plants of the differential hosts which had been growing in the greenhouse for the previous month were placed in the temperature cases maintained at 20°, 25°, and 30° C. The mean temperature of the greenhouse for the month was 24.2°. On January 24, the plants were inoculated by the spray method. A daily mean of 7.0 hours of sunshine prevailed during the period the plants were in the cases.

TABLE 13.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the stooling and jointing stages*

Form III

Experiment 12

Variety	Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	5	5	1	4	4	4
Marquis C. I. No. 3641	5	4	1	4	4	4
Kanred C. I. No. 5146	5	4	1	4	4	4
Turkey Red C. I. No. 1558	5	4	1	4	4	4
Kota C. I. No. 6248	5	3	...	4	4	...
Kubanka C. I. No. 1440	2	3	...	X	X	...
Einkorn	3	3	...	3	3	...
Khapli C. I. No. 4013	2	4	1	1	1	0;–1

Per cent of plants infected omitted owing to small number of plants.
For explanation of symbols used in this table see page 9.

On January 30, uredinia on some of the leaves were noted in the 25° and 30° C. cases, while 3 days later they began to appear on the plants in the 20° case. From this time on to the final reading, rust developed very rapidly. A summary of the results obtained is given in Table 13. It will be noted that only a trace of rust on some varieties occurred at 30°. Most of this rust was present on the lower leaves, with only an occasional secondary infection. Some telia were observed on several of the plants.

From a moderate to a considerable amount of rust developed at 25° C. Here 3 generations of rust were found, namely: the original infection with telia on the lower leaves, large pustules on the leaves half way up, and new pustules just appearing on the tip leaves. No stem infections were noted.

Rust was extremely abundant on all the plants at 20° C. Here also 3 generations of rust were present, and in addition some uredinia on the stems which were developing into telia. On the whole, a very high percentage of infection was obtained at 20° and 25°. These results are very similar to those obtained on seedling plants in Experiment 9.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE STOOLING AND JOINTING STAGES FORM IX

Experiment 13.—As in the previous experiment, the cans containing plants of the differential hosts which had been growing in the greenhouse for about 2½ months were placed in the temperature cases held at the temperatures of 5°, 10°, 15°, 20°, 25°, and 30° C., on February 9, 1923. The mean temperature of the greenhouse for the 2½ months was 17.2°. Three days later they were inoculated by the dusting method. A daily mean of 7.4 hours of sunshine prevailed during the period the plants were in the cases.

Five days after inoculation, uredinia were observed on some of the plants in the 25° and 30° C. cases. A few days later they were noted on the plants in the 20° case. Rust was not seen in the 15° case until about 2 weeks after inoculation. No rust developed on any of the plants held at the temperatures of 5° and 10°.

The results obtained are listed in Table 14 and are very similar to those obtained with Form IX in the seedling stage. In short, only a trace of rust on some varieties occurred at 30° C. More rust on more varieties occurred at 20° and 25°.

TABLE 14.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the stooling and jointing stages*

Form IX

Experiment 13

Variety	Degrees of infection at						Types of infection at					
	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	...	...	1	1	2	...	...	...	4	4	4	
Kanred C. I. No. 5146	...	...	...	...	...	...	...	...	...	...	...	
Turkey Red C. I. No. 1558	...	...	...	1	1–2	1	...	...	...	3	3–4	3
Arnautka C. I. No. 1493	...	...	1	1–3	2	1	...	...	4	4	4	3–4
Mindum C. I. No. 5296	...	...	...	...	1–3	1	...	...	...	...	X	X
Kubanka C. I. No. 1440	...	...	...	1	1–3	1	...	...	...	X	1	X
Einkorn C. I. No. 2433												
Khapli C. I. No. 4013	...	...	...	...	1	...	...	...	...	...	1	

Per cent of plants infected omitted owing to small number of plants.
For explanation of symbols used in this table see page 9.

while only a trace on 2 varieties was observed at 15°. Owing to the shortness of the period that the plants were held at these temperatures, only one generation of rust was present, which was strictly limited to the leaves. No telia were observed.

As no rust was observed on the plants in the 5° and 10° C. cases at the conclusion of the experiment almost 7 weeks after inoculation, the plants from the 5° case were set on a bench of the warm greenhouse for one week (mean temperature 23.0 C.). At the end of the week a trace of rust, with typical uredinia for the individual varieties respectively, was found on Little Club, Turkey Red, Arnautka, Kubanka, and Einkorn. Thus, as in Experiment 11, we have an instance of lengthened period incubation due to low temperature.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE HEADING STAGE

FORM III

Experiment 14.—On April 21, 1922, the cans containing the differential hosts which had been growing in the greenhouse since January 3 at a mean temperature of 17.8° C. were placed in the temperature cases of 20°, 25°, and 30°. Several days later they were inoculated by the dusting method. A daily mean of 8.0 hours of sunshine prevailed during the course of the experiment.

On April 27, a large number of ruptured uredinia were noted on the plants in the 25° C. case while only a few flecks appeared on the plants in the 20° case. At the conclusion of the experiment a heavy infection of the leaves was found

TABLE 15.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the heading stage*

Form III

Experiment 14

Variety	Degrees of infection at			Types of infection at		
	20°C.	25°C.	30°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	5	5	...	4	4	...
Marquis C. I. No. 3641	5	4	...	4	4	...
Kanred C. I. No. 5146	4	4	...	4	4	...
Turkey Red C. I. No. 1558	4	4	...	4	4	...
Kota C. I. No. 6248	2	3	...	3–4	4	...
Kubanka C. I. No. 1440	5	2	...	X	X	...
Einkorn	4	...	...	3–4	...	...
Khapli C. I. No. 4013	4	4	...	0;–1	0;–1	...

Per cent of plants infected omitted owing to small number of plants.
For explanation of symbols used in this table see page 9.

on the plants held at 25°, as can be seen in Table 15. Stem infection was limited to the spring wheats. A much heavier infection occurred on the plants held at 20° (Pls. 9 to 12). Here stem infection on the spring wheats was common and quite severe. In the 30° case, no rust was observed on any of the plants at any time during the course of the experiment.

INFLUENCE OF TEMPERATURE ON INFECTION AND DEVELOPMENT OF PUCCINIA GRAMINIS TRITICI ON WHEAT PLANTS AT THE HEADING STAGE FORM IX

Experiment 15.—As in the previous experiment, the plants were held in the greenhouse from November 28, 1922, to March 30, 1923, at a mean temperature of 17.8° C. and then transferred to the temperature cases maintained at 10°, 15°, 20°, 25°, and 30°. Several days after the plants had been placed in the cases, they were inoculated by the dusting method. A daily mean of 9.0 hours of sunshine prevailed during the course of the experiment. The results of the experiment are given in Table 16.

TABLE 16.—*Influence of temperature on infection and development of Puccinia graminis tritici on wheat plants at the heading stage*

Form IX

Experiment 15

Variety	Degrees of infection at					Types of infection a				
	10°C.	15°C.	20°C.	25°C.	30°C.	10°C.	15°C.	20°C.	25°C.	30°C.
Little Club C. I. No. 4066	4	4	2	2	...	4	4	4	4	
Kanred C. I. No. 5146	...	...	...	...		...		...		
Turkey Red C. I. No. 1558	...	1	...	...	...	...	3	...		
Arnautka C. I. No. 1493	4	4	2	1	...	4	4	4	3–4	
Mindum C. I. No. 5296	...	4	1	1	...	...	X	X	X	
Kubanka C. I. No. 1440	4	4	2	2	...	X	X	X	X	...
Einkorn C. I. No. 2433	...	...	...	...	...	...	...	...	...	..
Khapli C. I. No. 4013	2	2	2	1	...	1	1	1	1	

Per cent of plants infected omitted owing to small number of plants.
For explanation of symbols used in this table see page 9.

Rust was observed on the inoculated plants held at the various temperatures as follows: at 25° C. after 6 days, at 20° after 8 days, at 15° after 12 days, and at 10° after 20 days. No rust at all was observed during the course of the experiment at 30°, while only a sprinkling of rust occurred at 25°. A heavier infection occurred at 10° and 15° than at 20°. The failure of the winter wheat varieties to become infected can be explained thru the fact that they were completely shaded by the spring wheat varieties, which were headed and much taller. In fact, these varieties all made a rather poor growth owing to this condition. At 10°, rust pustules were present on the leaves, sheaths, and an occasional stem and glume. At 15°, more rust occurred on the stems than at 10°, while at 20° only 2 varieties had stems infected and only one at 25°.

Judging from the results obtained in Experiment 15, infection and the subsequent development of rust appears to be more favored by low temperatures. This may be due in part to the unfavorable temperature preventing the normal development of the plants at temperatures of 25° and higher.

INFLUENCE OF LOW TEMPERATURE ON THE PERIOD OF INCUBATION OF PUCCINIA GRAMINIS TRITICI ON TURKEY RED SEEDLINGS FORM IX

Experiment 16.—In Experiment 11, it was found that seedling plants, when inoculated and incubated for 48 hours at 23° C., did not produce any visible signs of infection over a period of 9 weeks, if the plants were thereafter kept at a temperature of 5°. However, when the plants were transferred to a temperature of 23° uredinia developed on some of the plants within a week.

Further in Experiment 13, it was shown that plants at the stooling stage, inoculated, incubated, and held at 5° C., produced no signs of infection over a period of 7 weeks. However, when these plants were removed to a higher temperature uredinia developed within a week on the leaves of some of the plants.

This experiment was carried out to supplement the results obtained in Experiments 11 and 13. On December 20, 1922, seed of Turkey Red wheat (C. I. No. 1558) was planted in pots which were placed on a bench in the warm house until the seedlings were 7 days old. They were then inoculated by hand and incubated at 25° C. for 48 hours. After

TABLE 17.—*Influence of low temperature on the period of incubation of Puccinia graminis tritici on Turkey Red seedlings*

Form IX

Experiment 16

Number of weeks from time of inoculation plants were kept in cold house	Set I		Set II		Set III	
	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf
1	27	1–4	13	1–2	7	1
2	53	1–2	7	2	20	1
3	27	1	20	1	13	2
4	47	1	27	1	0	0
5	47	1–3	20*	2	27*	1–3
6	33	1–10	7	1	0	0
7	33	1	13*	1–2	20§	1
8	40*	1–5	20§	1–10	20§	1
9	13*	1	33§	1	13§	1
10	53§	1	7§	1	27§	1

*One or two pustules visible when taken out of cold house.
§All pustules visible when taken out of cold house.

incubation the plants were divided into 3 sets and treated as follows:

Set I. Plants placed in the cold house immediately after incubation.
Set II. Plants benched in the warm house for 3 days and then transferred to the cold house.
Set III. Plants benched in the warm house for 5 days and then transferred to the cold house.

During the course of the experiment a temperature of 5° C. and below was maintained in the cold house. Occasionally the temperature dropped to freezing or slightly below.

At the end of every week, 3 pots of 6 plants each were withdrawn from each set in the cold house and placed on the bench in the warm house for one week, when the number of plants infected and the number of uredinia were noted.

To determine the host-parasite relation in the tissues of the plants, one or two leaves from plants of each set were fixed in Fleming weak solution every week when the plants were withdrawn from the cold house. A study of this material should determine in what form the parasite remains in the tissues during the dormant period of incubation.

The results of the experiment are tabulated in Table 17. It will be noted that in Set I a fairly uniform number of plants developed uredinia each week, after their transfer to a warm house. It was not until the eighth week that any pustules

were found on the plants in Set I in the cold house. After the tenth week the experiment was closed because uredinia were visible on some of the leaves of the plants in the cold house. In Set II a few pustules were visible on the plants in the cold house after 5 weeks and in a week or two more the pustules appeared on the majority of the infected plants. The same was true of the plants in Set III.

It must be borne in mind that before the plants were divided into the 3 lots, they were all inoculated in the same way; and had they been divided and then placed at a warm temperature, no doubt the percentage of infection would have been about the same. However, after the plants in Set I were transferred each week to the warm house an average of 38.7 per cent developed rust, while only 16.7 per cent and 14.7 per cent respectively were obtained in Sets II and III. In other words, the plants placed in the cold house immediately after 48 hours incubation produced a larger percentage of infection than the plants in which the parasite was further developed. Not only were a larger number of plants infected in Set I but a larger average number of pustules was obtained as contrasted with Set II and Set III. A low temperature apparently did not affect the viability of the parasite in the tissues of the leaves in Set I, owing to its undeveloped state; while where the parasite was further developed, as in the case of the infected plants in Set II and Set III, the low temperature did influence the viability of the parasite as judged by the number of plants infected and by the amount of rust which developed after they were transferred to the warm house.

After the experiment was discontinued, there remained a large number of plants in all 3 sets in the cold house. A

TABLE 18.—*Influence of low temperature on the period of incubation of Puccinia graminis tritici on Turkey Red seedlings*

Form IX

Experiment 16

Days after withdrawal	Set I		Set II		Set III	
	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf	Per cent of plants infected	Number of uredinia per leaf
0	27	...	12	...	25	...
7	37	1–15	15	1–5	25	1–3

count of the number of plants infected with the number of pustules per leaf was made for each set, and then all plants were placed on a bench in the warm house for 1 week, after which another count was made. The results are listed in Table 18.

No increase in the number of plants infected was noted on the plants in Set III. A 3 per cent increase was obtained on the plants in Set II and 10 per cent in the case of Set I. It will also be noted that the number of pustules per leaf is largest on the infected plants in Set I. The results again substantiate the statement made above in regard to the stage of development of the parasite in the tissues and its viability at low temperatures.

We may conclude from the results obtained that the period of incubation of stem rust can be extended over a long period by subjecting the inoculated plants to a temperature of 5° C. and that the length of this period depends upon the stage of development of the organism inside the tissue of the plant. These results are suggestive of the way overwintering might be successful under field conditions in certain localities of the winter wheat belt.

COMPARISON OF THE TYPES OF INFECTION OBTAINED WITH THE RESULTS OF OTHER INVESTIGATORS

As has been stated before, in no instance was the type of infection altered by any environmental factor or factors employed. The reaction of the biologic form to a definite host was always the same within certain limits. The results agree, with few exceptions, with those worked out by Stakman and Levine[1] and these exceptions are of minor importance.

During the work with Form III, the results checked with those of Stakman and Levine on all the differential hosts but two. Stakman and Levine using a Minnesota selection Kubanka (C. I. No. 2094) report a range of infection on this host from 0 to 2 with a mean of 1+ when infected with Form III. In our investigation Kubanka C. I. No. 1440 was employed most frequently but instead of obtaining a reaction similar to Stakman and Levine's there developed in all cases a heterogeneous type of infection. Furthermore, on using various Cereal Investigations numbers of Kubanka including C. I. No. 2094, the same results were obtained. Similarly with Speltz Marz, Stakman and Levine reported a range of infec-

[1] Loc. cit.

tion between 0 and 1 + + with a mean of 1 = with Form III, whereas we obtained a mean of 3. However, neither the Cereal Investigations accession number nor the original source of the seed of this differential host was known, so that we cannot draw any comparisons.

Again, with Form IX, Kubanka reacted similarly, and a heterogeneous type of infection was obtained irrespective of the Cereal Investigations number used or the locality from which the seed was obtained. Stakman and Levine's results show that their Kubanka (C. I. No. 2094) has a type of infection of 4. Mindum also produced a heterogeneous type of infection with Form IX instead of type 4 as reported by Stakman and Levine. The latter have used a pure line selection of Mindum (Minn. No. 470), the original seed having been obtained from the Section of Plant Breeding of the Minnesota Agricultural Experiment Station.

Owing to the fact that only one form of rust was introduced into the greenhouse each season, the results obtained cannot be attributed to a mixture of forms. They may perhaps be explained by the fact that the stock material furnished the writer by Dr. Stakman and Mr. Levine was not from the original isolation which was used by them to make their test, but from a reisolation obtained in the field at another time. However, these variations in results are of minor importance.

From the results obtained, we can conclude that under the environmental conditions to which both the host and the parasite have been subjected the type of infection remained constant and that, with the minor exceptions noted above they are in complete accord with those obtained by Stakman and Levine. By "constant" the writer does not mean that the types of infection are fixed within narrow lines but that a resistant plant never becomes susceptible or vice versa. Or, stated in another way, a differential host may react to a biologic form within a range of from 0 to 2, or 3 to 4, but never from 0 to 3, or 1 to 4, or even 2 to 3.

DISCUSSION

While one of the aims of the present investigation was to determine whether the 2 biologic forms of *Puccinia graminis tritici* studied remained constant under various environmental conditions, it is only one phase of a study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. It is essential that a

study be made of the environmental factors influencing, not only the growth of the host plants at various stages of growth but also infection and the development of the disease, to determine under what environmental conditions in the field the red spore stage could propagate itself from season to season in the absence of the common barberry, in view of the fact that the barberry is being eradicated in the grain growing states of the Middle West. Since the results of all the experiments showed conclusively that the types of infection cannot be radically changed by the conditions to which the host and parasite are submitted, the discussion of the influence of environmental factors on the growth of the host plant and on infection and development of the disease will be taken up.

During the course of the investigation wheat plants at the seedling, stooling, jointing, and heading stages have been studied. It has been shown that with temperatures of 25° C. and below, the per cent of germination was the same provided the time element was considered. As far as could be determined from the limited population used, seed of all the differential hosts germinated about equally well at all these temperatures. A soil and air temperature of 30° in all instances decreased the per cent of germination of all the differential hosts employed. This was especially true of Kanred and Turkey Red.

For the best development of the seedlings subsequent to germination and emergence, the optimum temperatures appeared to be at 15° and 20° C. Temperatures of 25° and 30° were too high and their influence on the seedlings resulted in an excessive elongated mesocotyl. A good growth was obtained at 5° and 10° but it was extremely slow.

Similarly at the stooling, jointing, and heading stages the best development of the plants occurred at 15° and 20° C. A temperature of 30° produced stunted plants and seemed to inhibit both stooling and heading. At 25° stooling was inhibited, but this temperature favored the more rapid heading of the plants. Until more data have been obtained on the influence of not only temperature but other environmental factors as well on the development of wheat plants at different stages of growth, no attempt will be made to correlate the results of greenhouse studies with what occurs under field conditions.

The conditions essential for the successful infection of wheat plants by urediniospores are a suitable temperature free moisture or a very high relative humidity, and an actively growing plant. In speaking of infection, one must distinguish between the period of initial infection and the period of incubation. The writer[1] has defined these periods as follows: "By the period of initial infection is meant the time required by the organism after it reaches a leaf, to enter the stomata or, in case of wounds, the tissue of the plant. The period of incubation, on the other hand, is the period extending from initial infection until the disease is visible."

The object of the first 4 experiments was to determine the temperature suitable for initial infection. The optimum temperature for initial infection for Form III appeared to be 25° C., while in the case of Form IX it is nearer 20°. A much higher percentage of infection was obtained with Form III at 30° than with Form IX. However, the lower temperatures appeared to be more favorable for initial infection for Form IX than for Form III. In other words, the range of temperatures suitable for initial infection by Form IX was about 5° lower than for Form III. The various incubation temperatures employed influenced not only initial infection but also the period of incubation, in that the lower incubation temperatures retarded the period of incubation.

Seedling plants grown at the various temperatures, inoculated and held at these same temperatures until the conclusion of the experiment, yielded quite different results. No infection was obtained at 10° C. and below. Only a few plants of some differential hosts were infected at 15° and 30° The optimum temperatures for infection in these experiments were between 20° and 25° for both forms. The period of incubation varied with the temperature, being shortest at 30° and longest at 15°.

Similarly plants at the stooling and jointing stages became most heavily infected with rust at 20° and 25° C. No infection was obtained at 5° and 10°. Only an occasional plant was infected with a trace of rust at 15° and 30°.

Plants at the heading stage seemed to have a lower optimum temperature for infection in that no rust whatsoever developed at 30° C. while at 10° some few plants were infected. In the case of Form III almost as heavy an infection

[1] Peltier, G. L. Influence of Temperature and Humidity on the Growth of *Pseudomonas citri* and its Host Plants and on Infection and Development of the Disease. Jour. Agr. Research **20**; 447-506, 1920.

was produced at 25° as at 20°, while the plants inoculated with Form IX were most heavily infected at 15°. As in former experiments, the period of incubation was shortest at the high temperatures and longest at the lower temperatures.

In conclusion, it might be stated in a general way that there is a wider temperature range for infection of seedling plants by rust than of plants in the heading stage. This is especially true of the higher temperatures. The temperatures at which the plants make their best growth are generally the most favorable for the best development of the disease.

In Experiment 11, seedling plants were inoculated and incubated at the optimum temperature for initial infection and after incubation placed at the various temperatures. As has been pointed out, no material differences were noted at temperatures of 15° C. and above, on the period of incubation. However, plants held at 5° for 9 weeks did not develop any rust until they were transferred to a higher temperature. On the other hand, the incubation period of the rust on plants placed in the 10°, 15°, 20°, 25°, and 30° cases was 18, 16, 11, 8, and 8 days respectively. In this instance we had a lengthened period of incubation, due solely to a low temperature which slows down the normal functions of the host and parasite. However, immediately upon the speeding up of the plant functions by their transfer to a higher temperature, the parasite also becomes active. Perhaps under suitable conditions the period of incubation could be lengthened over a period of several months.

In Experiment 13, plants inoculated at 5° C. and maintained at this temperature for 7 weeks developed no rust until they were transferred to a higher temperature. In this instance the question naturally arises whether initial infection can take place at 5°, as we have no direct evidence that the urediniospores can germinate and enter the host plant at this temperature. The writer[1] obtained similar results in his Citrus canker investigation in that Citrus plants inoculated at the temperatures of 5°, 10°, and 15° produced no signs of infection until they were transferred to a higher temperature.

Experiment 14 was carried out to supplement the results obtained in Experiment 11. The results showed that a rather uniform number of plants that immediately after incubation

[1] Loc. cit.

were placed at a low temperature, developed rust each week when brought out of the cold house. No rust was visible on these plants in the cold house until the eighth week. Plants of the other 2 sets when brought out of the cold house did not produce as high an average per cent of infection, nor as many uredinia on the plants as in Set I.

From the results of all these experiments there can be no question but that the period of incubation of stem rust can be extended over a long period at a low temperature. The length of this period depends not only upon the temperature but also on the stage of development of the organism in the leaf tissues of the host. These results are very suggestive of the way overwintering of the uredinial stage might occur in some localities of the winter wheat belt.

Initial infection can take place under conditions which do not favor the development of the disease. Furthermore, it may occur and the organism remain quiescent in the tissues for long periods without any signs of the disease being manifested. In fact, we may assume that there are occasions when initial infection takes place without the subsequent development of the disease, because of unfavorable external and internal conditions for its development. Thus, initial infection requires a definite set of conditions entirely different from those required for the development of the organism after it enters the host plant. About the same conclusions were drawn in the writer's investigations [1] of the influence of temperature on infection and development of Citrus canker caused by a bacterium.

In presenting the experimental data, the writer has referred to the influence of sunshine on the per cent of infection and amount of rust. It will also be noted that under each experiment the total or the daily mean hours of actual sunshine have been given for the period of the experiment. Judging from the numerous observations made during the course of this investigation, sunshine did not have a direct relation to the parasite. However, sunshine had a direct influence on the growth of the plants in that the plants growing in the experiments when the hours of sunshine were great, produced ranker, greener, and more rapidly growing plants than in those experiments where the hours of sunshine were low.

[1] Loc. cit.

When the hours of sunshine were greater, other factors being equal, a higher percentage of infection and a larger number of uredinia per leaf resulted. Thus, we do have an indirect influence on the parasite, thru the better growing conditions of the host. The writer does not know whether it is the duration or the intensity of sunshine, or both, that enhances this relation, altho from the observations which have been made, it appears that duration of sunshine is more important than intensity.

For some reason, Form IX did not have the ability to infect the differential hosts as readily as Form III. This was noticeable in all the experiments but one, where the per cent and degrees of infection are given. In this one experiment (Number 8) the per cent and degrees of infection are on the average as high or higher than those obtained with Form III. However, it will be noted that during the course of the experiment 53.8 hours more of sunshine prevailed than during the period of Experiment 7. In all the other experiments where Form IX was used, the total or daily mean hours of sunshine was less than in the experiments where Form III was used. Whether we can correlate the evident differences between the infecting power of these 2 forms solely because a smaller number of hours of sunshine prevailed could not be determined, but there was no question but that fewer hours of sunshine may have played some part.

So far as the observations of the writer went, there was no evident difference between the resistant and the susceptible varieties in the length of time from initial infection until flecking appeared on the plants. However, unruptured pustules generally developed in a shorter period of time on the susceptible plants than on the resistant varieties.

At first thought one would suppose that, as a whole, the percentage and degrees of infection would be higher on the susceptible hosts than on those which were resistant. However, such is not always the case. A comparison of results obtained with Form III and Form IX, on Kanred, Arnautka, and Emmer and others show that, irrespective of whether they were susceptible or resistant to these forms, the percentage and degrees of infection are about the same when the other factors which enter in are considered.

Further, Khapli is considered the most resistant of the differential hosts to the 37 biologic forms of *Puccinia graminis tritici*. Still, if the average percentage of infected plants and degrees of infection are totaled for all the experiments,

it will be found that a higher percentage of infected plants was obtained with Khapli than with any of the most susceptible hosts. However, the fact that a differential host is easily infected does not necessarily mean that it will always prove susceptible. The real test of resistance takes place after the organism has entered the stomata of the host plant; and the type of infection more than the degree of infection, or the percentage of infected individuals, serves as the correct criterion for the determination whether a host plant is resistant or susceptible.

Temperature case showing construction, thermostat and other accessories.

PLATE 2

Plates 2–12 illustrate the results of inoculations with the biologic Forms III and IX of *Puccinia graminis tritici* on the differential hosts, showing the characteristic types of infection. The photographs from which these reproductions were made were obtained with a VIIa convertible Protar lens F:77 and a Wratten K-2 Filter, with a 2½ minute exposure and an F-22 stop. A constant source of artificial light was employed consisting of three 200-Watt Mazda lights placed around the camera stand.

For the dark background a good grade of velvet was used. Material to be photographed was brought into the dark room in a fresh condition and photographed immediately. All reproductions are natural size.

A. Form III on Little Club C. I. No. 4066 from Moccasin, Mont., and Little Club C. I. No. 4066 from Moro, Ore.

B. Form IX on Little Club C. I. No. 4066 from Moccasin, Mont., and Little Club C. I. No. 4066 from Moro, Ore.

C. Form III on Marquis C. I. No. 3641 from Moccasin, Mont., and Marquis C. I. No. 3276 from Aberdeen, Ida.

D. Form IX on Marquis C. I. No. 3641 from Moccasin, Mont., and Marquis C. I. No. 3276 from Aberdeen, Ida.

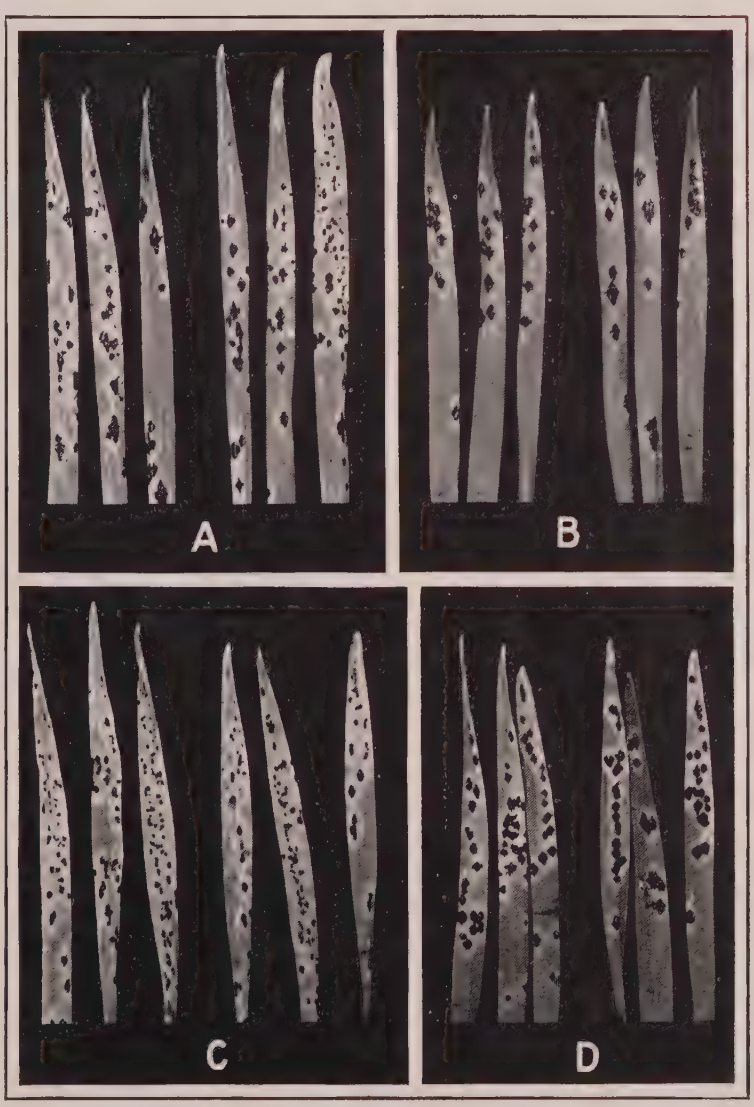
A
B
C
D

PLATE 3

A. Form III on Kanred C. I. No. 5146 from Moccasin, Mont., and Kanred C. I. No. 5146 from Manhattan, Kan.

B. Form IX on Kanred C. I. No. 5146 from Moccasin, Mont., and Kanred C. I. No. 5146 from Manhattan, Kan.

C. Form III on Turkey Red C. I. No. 1558 from Moccasion, Mont., and Turkey Red C. I. No. 1571 from Moro, Ore.

D. Form IX on Turkey Red C. I. No. 1558 from Moccasin, Mont., and Turkey Red C. I. No. 1571 from Moro, Ore.

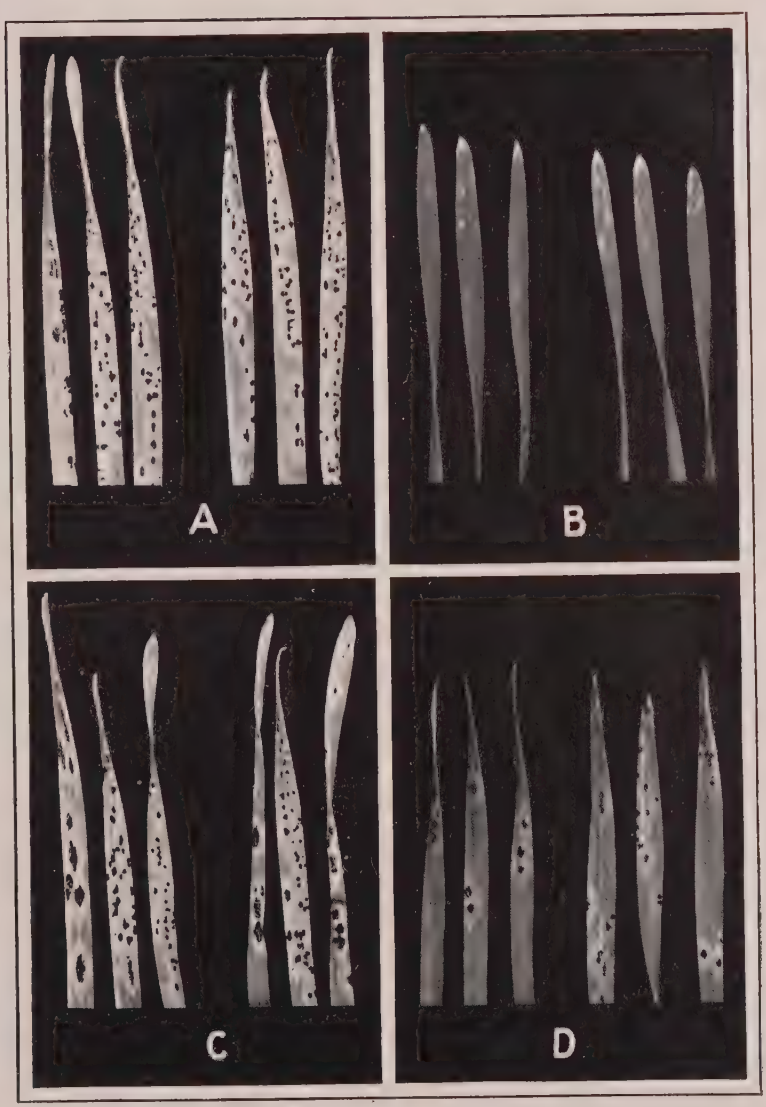
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PLATE 4

A. Form III on Kota C. I. No. 6248 from Moccasin, Mont., and Kota C. I. 5878 from Dickinson, N. D.

B. Form IX on Kota C. I. No. 6248 from Moccasin, Mont., and Kota C. I. No. 5878 from Dickinson, N. D.

C. Form III on Arnautka C. I. No. 4064 from Moccasin, Mont., and Arnautka C. I. No. 4072 from Corvallis, Ore.

D. Form IX on Arnautka C. I. No. 4064 from Moccasin, Mont., and Arnautka C. I. No. 4072 from Corvallis, Ore.

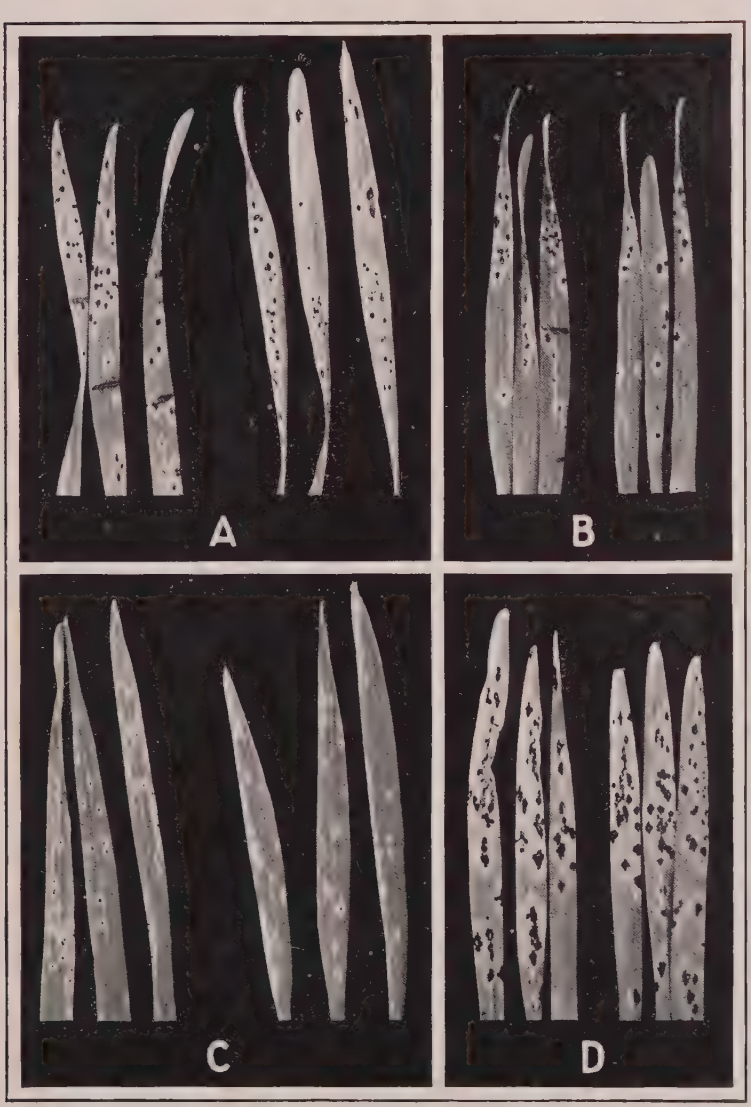
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PLATE 5

A. Form III on Mindum C. I. No. 5296 from Cheyenne, Wyo., and Mindum C. I. No. 5296 from Dickinson, N. D.

B. Form IX on Mindum C. I. No. 5296 from Cheyenne, Wyo., and Mindum C. I. No. 5296 from Dickinson, N. D.

C. Form III on Speltz Marz.

D. Form IX on Speltz Marz, and Speltz Marz C. I. No. 6236.

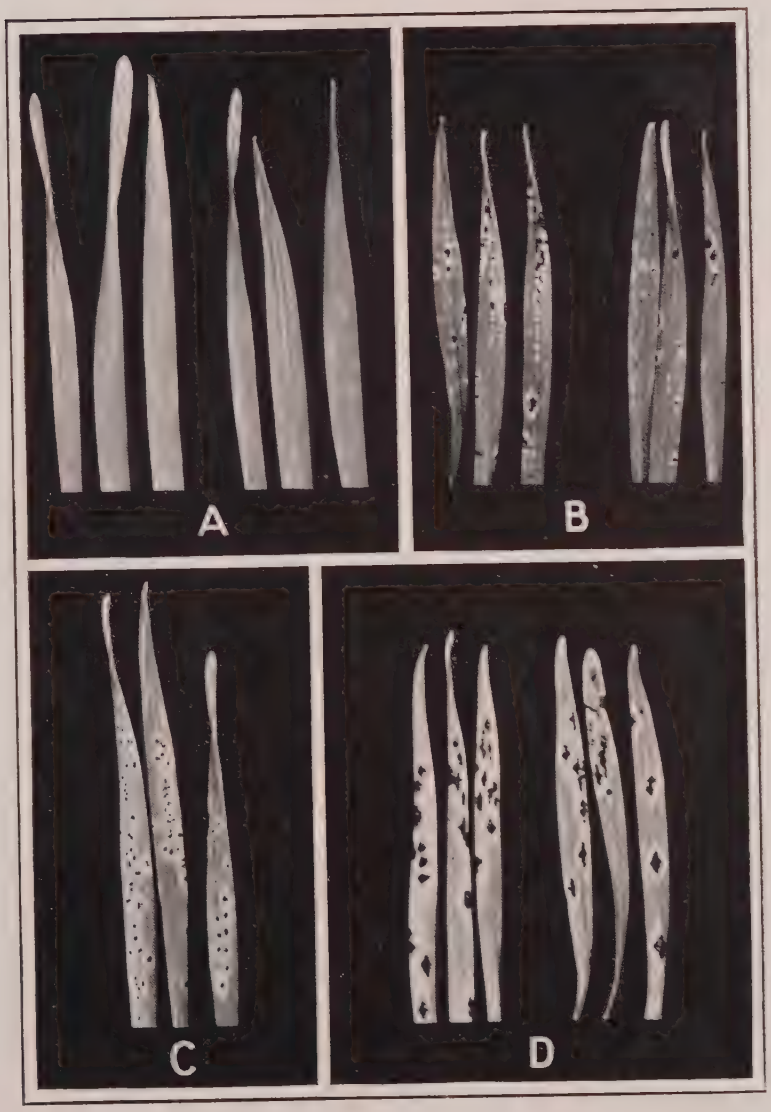
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PLATE 6

A. Form III on Kubanka C. I. No. 1440 from Dickinson, N. D., and Kubanka C. I. No. 2094.

B. Form IX on Kubanka C. I. 1440 from Dickinson, N. D., and Kubanka C. I. No. 2094.

C. Form III on Acme C. I. No. 5284 from Moccasin, Mont., and Acme C. I. No. 5284 from Mandan, N. D.

D. Form IX on Acme C. I. No. 5284 from Moccasin, Mont., and Acme C. I. No. 5284 from Mandan, N. D.

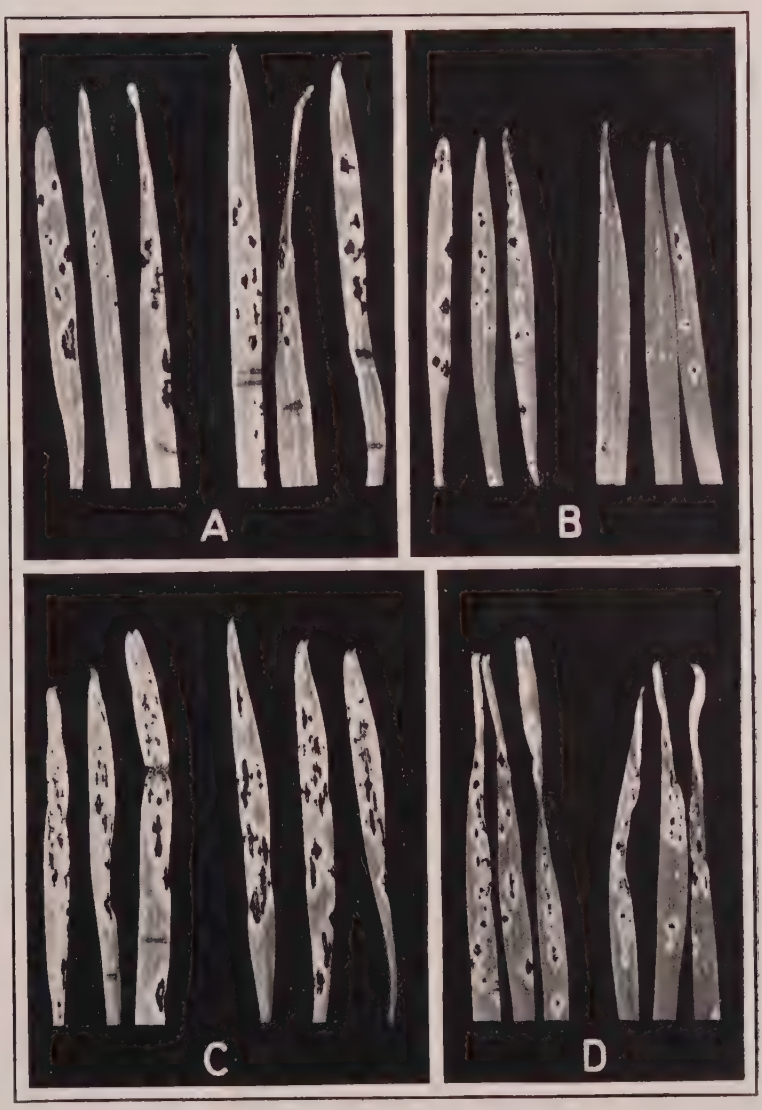
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PLATE 7

A. Form III on Einkorn from Dickinson, N. D., and Einkorn C. I. No. 2433 from Dickinson, N. D.

B. Form IX on Einkorn from Dickinson, N. D., and Einkorn C. I. No. 2433 from Dickinson, N. D.

C. Form III on Emmer C. I. No. 3686 from Moccasin, Mont., and C. I. No. 3686 from St. Paul, Minn.

D. Form IX on Emmer C. I. No. 3686 from Moccasin, Mont., and C. I. No. 3686 from St. Paul, Minn.

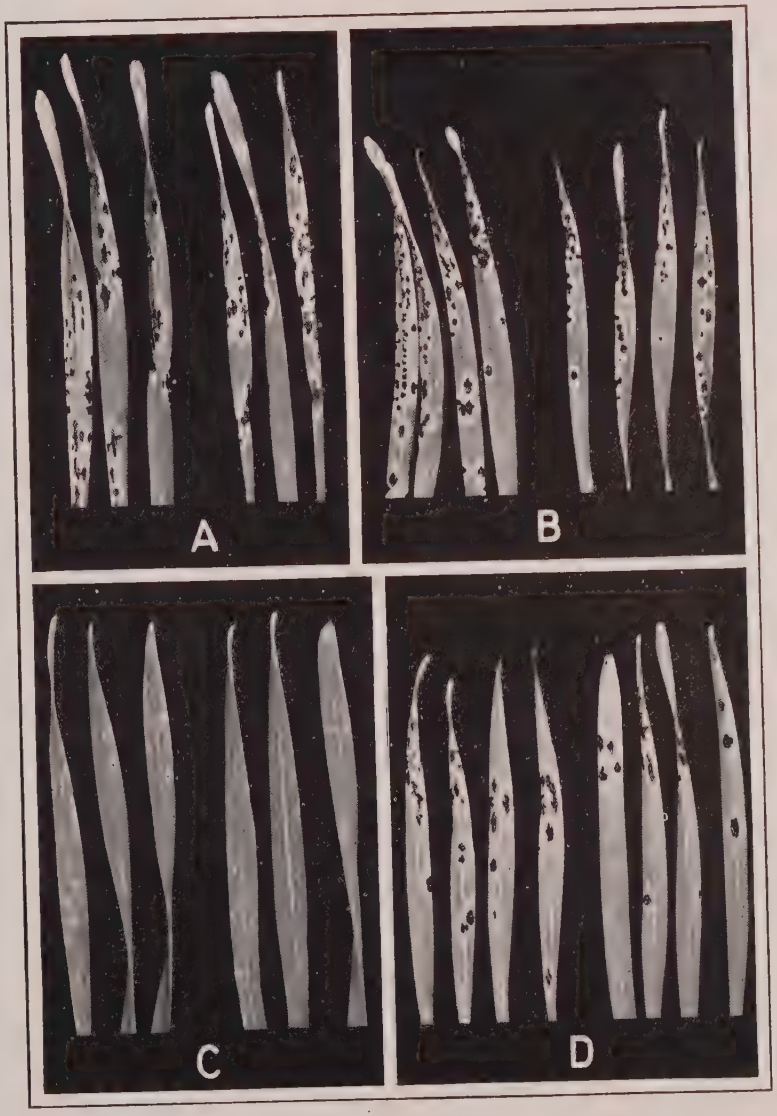
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PLATE 8

A. Form III on Khapli C. I. No. 4013 from Moccasin, Mont., and Khapli C. I. No. 4013 from Highmore, S. D.

B. Form IX on Khapli C. I. No. 4013 from Moccasin, Mont., and Khapli C. I. No. 4013 from Highmore, S. D.

C. Form IX on Blackhull from Lincoln, Neb.

D. Form IX on Crimean C. I. No. 1435 from Lincoln, Neb.

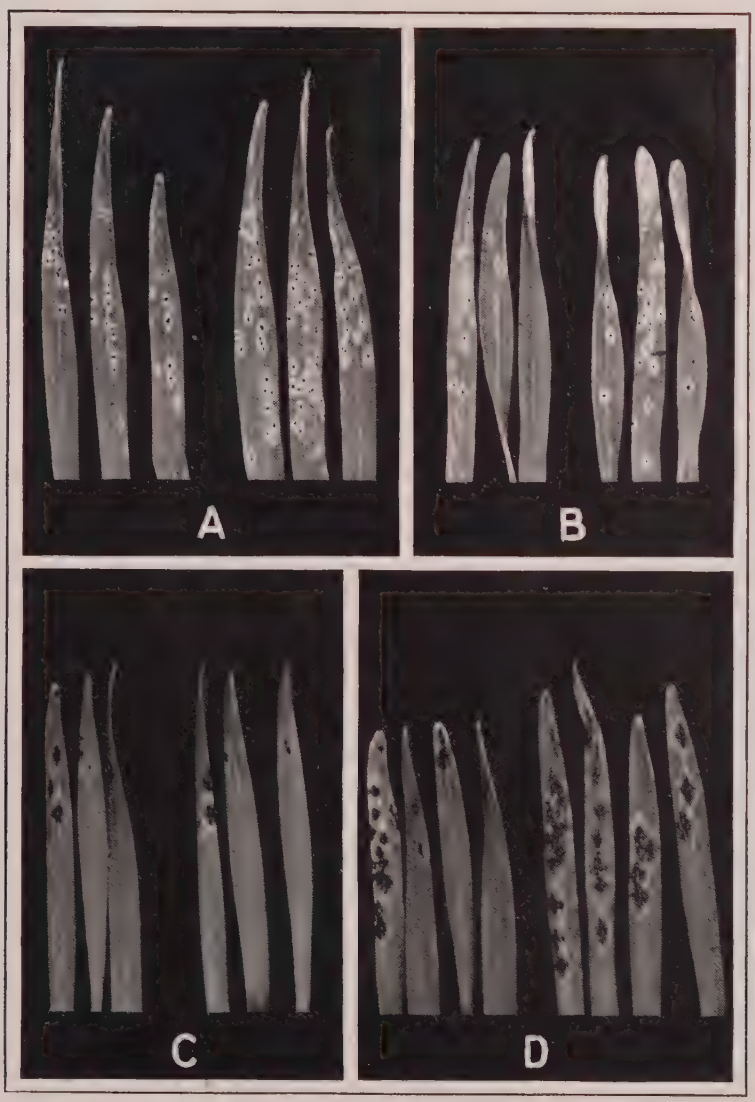
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PLATE 9

A. Form III on leaves and stems of Little Club C. I. No. 4066, at heading stage, at a temperature of 20° C., showing degree and type of infection.

B. Form III on leaves of Little Club C. I. No. 4066 at heading stage at a temperature of 25° C. showing degree and type of infection.

C. Form III on leaves and stems of Marquis C. I. No. 3641 at heading stage, at a temperature of 20° C., showing degree and type of infection.

D. Form III on leaves and stems of Marquis, C. I. No. 3641 at heading stage, at a temperature of 25° C., showing degree and type of infection.


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PLATE 10

A. Form III on leaves of Kanred C. I. No. 5146 at jointing stage, at a temperature of 20° C., showing degree and type of infection.

B. Form III on leaves of Kanred C. I. No. 5146 at jointing stage, at a temperature of 25° C., showing degree and type of infection.

C. Form III on leaves of Turkey Red C. I. No. 1558 at jointing stage at a temperature of 20° C., showing degree and type of infection.

D. Form III on leaves of Turkey Red C. I. No. 1558 at jointing stage at temperature of 25° C., showing degree and type of infection.

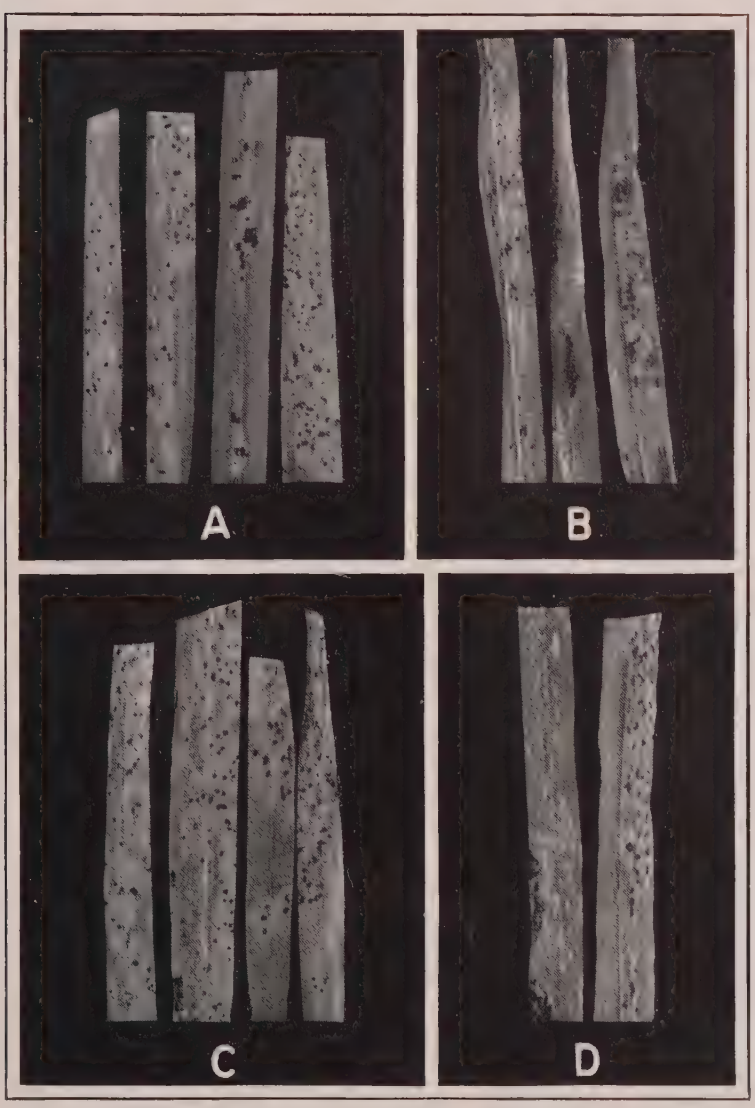
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PLATE 11

A. Form III on leaves and stems of Kota C. I. No. 6248 at heading stage at a temperature of 20° C., showing degree and type of infection.

B. Form III on leaves of Kota C. I. No. 6248 at heading stage at a temperature of 25° C., showing degree and type of infection.

C. Form III on leaves and stems of Kubanka C. I. No. 1440 at heading stage at a temperature of 20° C., showing degree and type of infection.

D. Form III on leaf of Kubanka C. I. No. 1440 at heading stage at a temperature of 25° C., showing degree and type of infection.

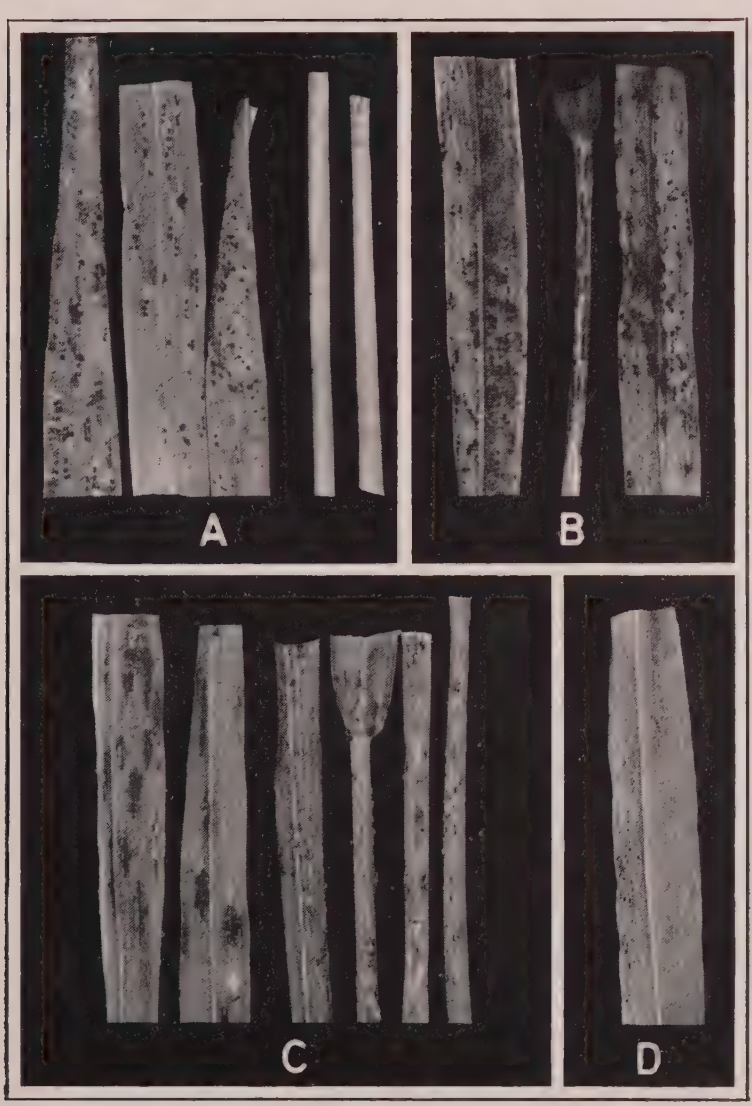
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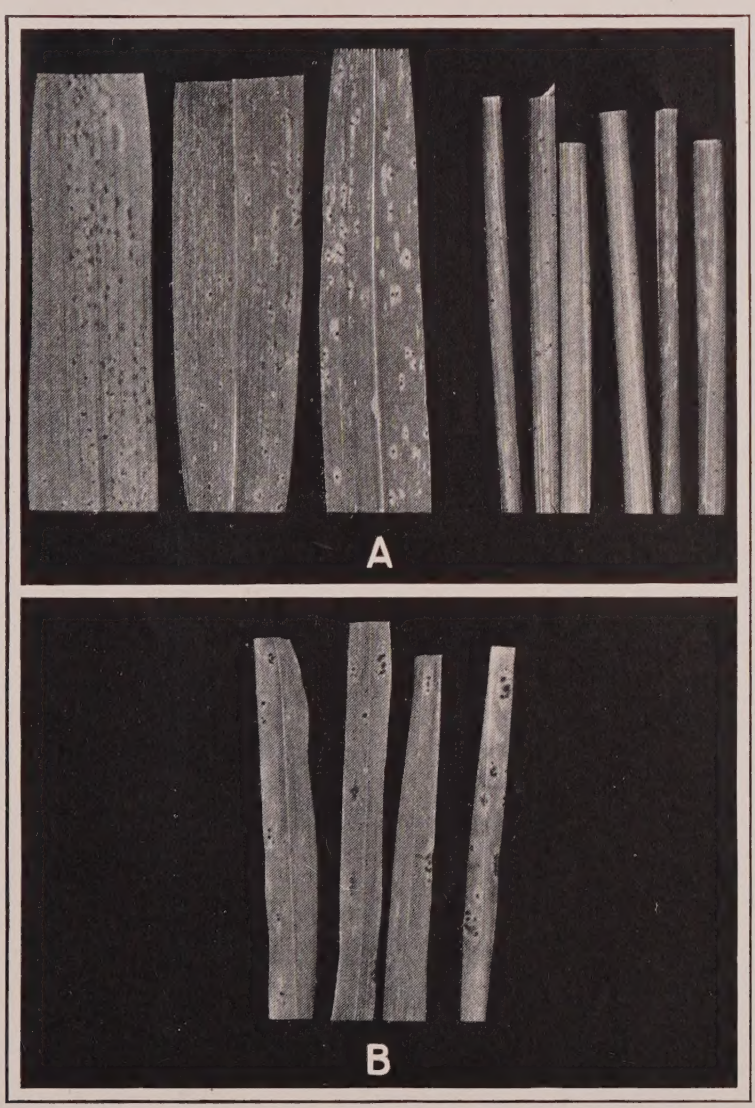
PLATE 12

A. Form III on leaves and stem of Khapli C. I. No. 4013 at heading stage at a temperature of 20° C., showing degree and type of infection.

B. Form III on leaves of Einkorn at jointing stage at a temperature of 20° C., showing degree and type of infection.


A
B

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